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# EXTERIOR WALL CONSTRUCTION IN HIGH-RISE BUILDINGS

## BRICK VENEER ON CONCRETE MASONRY OR STEEL STUD WALL SYSTEMS

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# EXTERIOR WALL CONSTRUCTION IN HIGH-RISE BUILDINGS

## BRICK VENEER ON CONCRETE MASONRY OR STEEL STUD WALL SYSTEMS

This publication was prepared by
R. G. Drysdale, P. Eng., McMaster University and
G. T. Suter, P. Eng., Suter Keller Inc.

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# *PREFACE AND ACKNOWLEDGEMENTS*

In 1981 Canada Mortgage and Housing Corporation published a timely Advisory Document on *Exterior Wall Construction in High-Rise Buildings* authored by W.G. Plewes. For the first time in Canada, this publication focused attention to a considerable depth on what might be termed *modern masonry cavity walls and veneers* on frame buildings. While such exterior wall constructions had come into wide use, a growing number of performance problems necessitated a comprehensive look at such issues as design, construction, supervision and inspection, which potentially underlie such problems.

This new publication serves partly as an update of the 1981 document but is mainly a vehicle to discuss the best design and construction practices for both the long-established brick veneer/concrete masonry (BV/CM) and the relatively new brick veneer/steel stud (BV/SS) wall systems. Especially over the past 10 years, BV/SS walls have become more widely used in Canada as an economical building enclosure system. Based on a CMHC sponsored field survey *(Brick Veneer/Steel Stud Wall Design and Construction Practices in Canada-Results of a 1986 Survey),* the authors' personal observations, and overall review of this topic, however, the construction of these walls has preceded the development of adequate design, construction and inspection standards. This situation has, in turn, led to many sectors of the building industry being concerned over the long-term safety, serviceability, and durability of this form of construction.

It is the aim of this publication to discuss critical design, construction and inspection issues which may affect the long-term performance of both the BV/SS and BV/CM wall systems.

The authors acknowledge with thanks the permission granted by CMHC and W.G. Plewes to include portions of text and selected diagrams from the 1981 Advisory Document.

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# PART 1 INTRODUCTION TO STUDY AND VENEER WALL SYSTEMS

## CHAPTER 1

## INTRODUCTION

### 1.1 PURPOSE

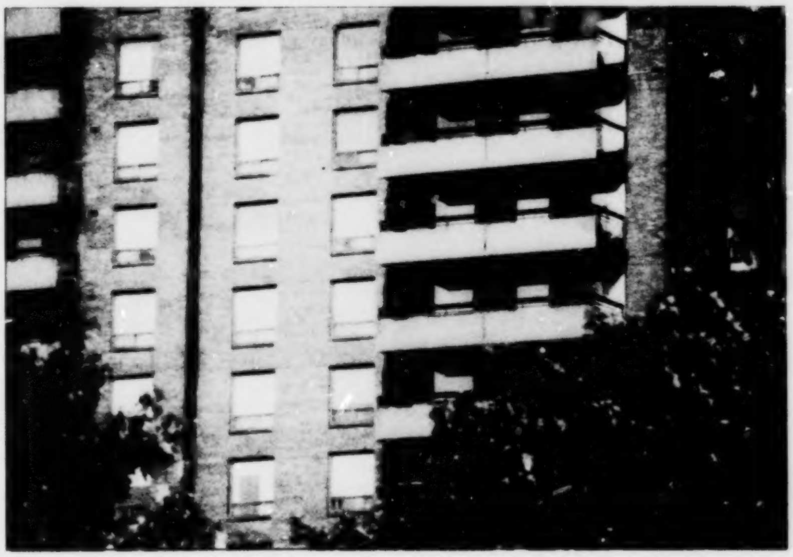
Since the 1950s, brick veneer walls have been widely used in Canada as part of economical building enclosures, especially in residential high-rise construction. Two typical examples are illustrated in Figure 1.1. Such walls have certain advantages which have made them popular:

- moisture penetrating the brick facing of the wall can drain into a cavity and then be conducted back to the exterior by suitable flashings and openings; and
- in some instances, insulation may be placed conveniently in the cavity rather than at the interior of the wall.

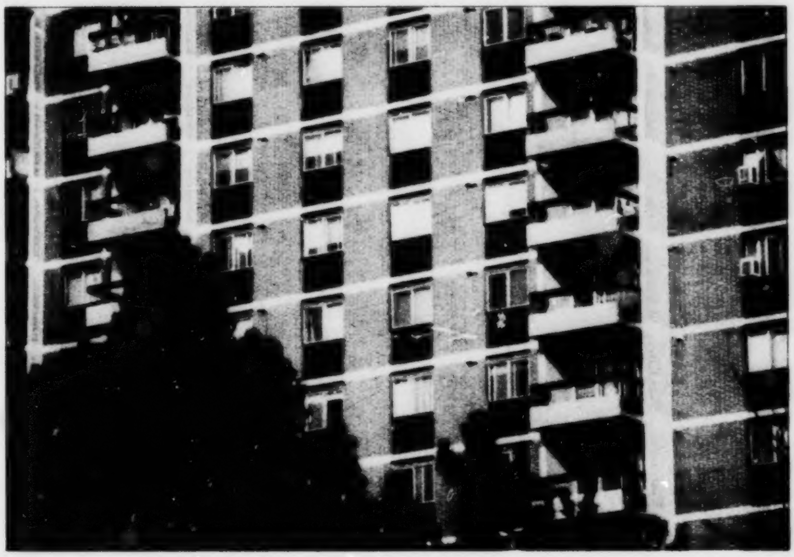
Well built veneer walls have performed well. However, in recent years, faults in design or construction have too frequently led to cladding distress and resulted in expensive repairs.[1] These errors are largely due to a lack of observance of good design principles and good construction practices.[2,3,4,5] Construction practices must reflect varying regional requirements according to widely differing climatic conditions across Canada.

Rain leakage is the most common problem, [6,7,8,9,10] but not the only one. Condensation of moisture from the interior also occurs within walls, as does spalling of bricks, buckling of panels due to moisture expansion, frame shortening and thermally produced dimensional changes, and corroding of connectors (Figures 1.2 to 1.5). Such incidents have been reported in a number of countries other than Canada.[11,12]

Although this publication presents many design and construction details, it is an Advisory Document; it is neither a design nor a construction manual. Its purpose is to point out specific contributing causes of exterior wall serviceability failures in high-rise buildings. To help avoid such problems in the future, wall design principles are discussed and illustrated.



a) Veneer supported on steel shelf angles hidden from view



▼ Figure 1.1 Appearance of high-rise residential buildings employing brick veneer wall systems

b) Veneer supported on floor slabs which extend to the exterior of the building

The drawings are not fully developed designs, particularly in the matters of sizes and selection of materials; rather, they are schematic designs to facilitate discussion of the factors affecting performance.

▼ *Figure 1.2 Efflorescence staining from air leakage and internal condensation*

Building science is an extensive technology today, but to keep the text within manageable limits, complicated explanations have been avoided as much as possible. Other reports provide comprehensive treatment.[13,14] Where appropriate, reference is made to other publications and to the design and construction items covered by requirements of the National Building Code of Canada, Residential Standards, and CSA Standards. Relevant codes and standards are included in the bibliography.

## *1.2 BACKGROUND AND SCOPE*

In Canada today, two types of backup wall systems for brick veneer wall construction are commonly used in high-rise construction. The two backup systems are the masonry concrete block (CM) and the steel stud (SS) forms of construction. While block backup has been widely used for decades, the newer steel stud backup system came on the Canadian market only in the 1970s. When CMHC published the Advisory Document entitled *Exterior Wall Construction in High-Rise Buildings*[15] in 1981, the steel stud backup system was still very much in its infancy in Canada and hence the publication emphasized issues related to the block backup system.

A recent CMHC sponsored survey of brick veneer/ steel stud building practices[16,17] found that design and construction practices vary widely and that both the designer and contractor seek guidance about the best design and construction practices. Clearly there is a need for an updated Advisory Document which addresses all important design and construction issues for both the brick veneer/ concrete masonry (BV/CM) and brick veneer/ steel stud (BV/SS) enclosure systems. This then is the overall goal of this publication. Sub-goals include the following:

- discussion of the rain screen principle and its relation to rain penetration of walls;
- documentation of the best current design, construction, and inspection practices;
- presentation of common deficiencies and remedial measures;
- presentation of suggested details; and
- listing of relevant code and standards requirements.

## *1.3 SPECIAL ASPECTS OF HIGH-RISE BUILDINGS*

By regulation of the National Building Code of Canada,[18] buildings over three storeys high must be designed and built under the provisions of Parts 1 to 8 of the NBC rather than Part 9, or according to the provisions of Residential Standards.[19] In this document, therefore, high-rise buildings are taken to mean those of four or more storeys.

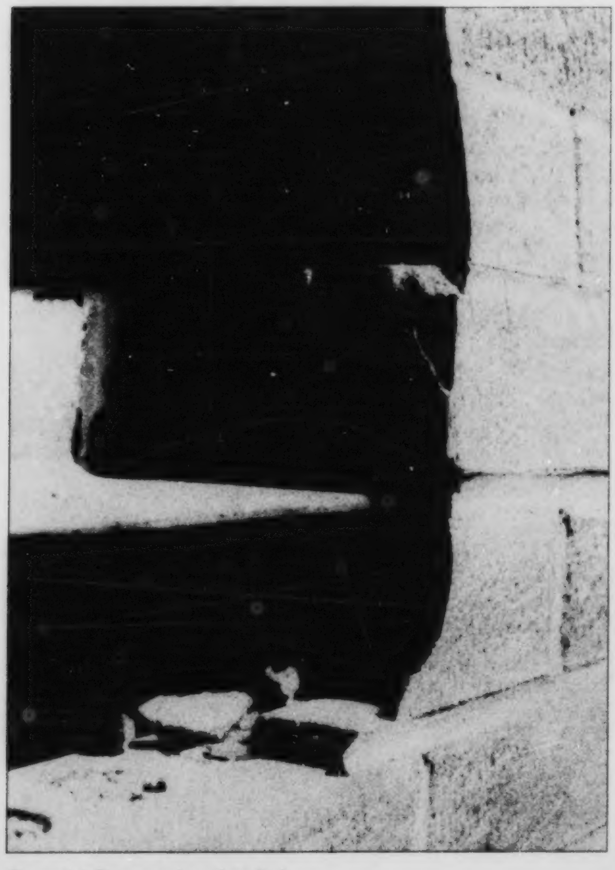
Although many aspects of the design and construction of high- and low-rise buildings are the same, certain features of high-rise buildings are more critical and require closer attention:

- Because of their height, high-rise buildings are more exposed to the elements, such as driving rain.
- Pressure differences across walls increase with the height of the building and cause greater air leakage.[20]
- Because of their size, close inspection of highrises both during and after construction is more difficult.
- Large portions of the building are less readily accessible, making repairs more difficult and expensive.
- There is a greater repetition of detail, so that failure of a component design item or construction procedure may occur many times, necessitating expensive remedial repairs.
- Expansions and contractions due to moisture and thermal changes in a vertical direction are magnified.
- There are often greater lateral movements in the structural frame.
- When distress occurs, it can endanger the safety of the public.

▼ *Figure 1.3 Spalling of bricks at a shelf angle due to lack of a horizontal movement joint. Frame shortening and brick veneer expansion led to unintentional stressing of the veneer*

## 1.4 ENVIRONMENTAL CONDITIONS

For the satisfactory long-term performance of cladding systems, differing environmental conditions must be taken into account in the choice of materials, design details, as well as construction and inspection requirements.



▼ Figure 1.4 Close-up view of spalled brick at a shelf angle due to lack of a horizontal movement joint

Differing environmental conditions which come into play across Canada include moisture, wind, temperature (especially temperature fluctuations resulting in a large number of freeze-thaw cycles), and corrosive agents, such as salt spray in a marine environment or certain industrial pollutants.

Unfortunately for the designer of enclosure systems, no detailed information which divides Canada geographically into regions according to the severity of environmental conditions is available. A brief overview of widely differing corrosive conditions across Canada has been presented in the recent Canadian Standards Association publication, Connectors for Masonry.[21] Although the information is not directly related to the performance of cladding systems and their components, it is nevertheless useful in pointing out the wide variation in so-called indices of atmospheric corrosion across Canada.

In the absence of more detailed guidelines to enable the designer to cope with different environmental conditions which can significantly influence the long-term performance of enclosure systems, it is recommended to:

- at least consider that differing conditions exist and that, for example, material requirements and design details may have to be significantly different for instance for a project in Halifax as compared to Calgary;
- check local performance records; and
- assess the potential of increasing corrosive conditions in a given region where industrial development, for instance, may introduce more corrosive environments in the future.

## 1.5 AUDIENCE

While the publication is broadly aimed at designers and contractors, the interested audience will include the project architects, project structural engineers, general contractors, sub-contractors, manufacturers, building scientists and building officials.

▼ *Figure 1.5 Corroded ties removed from cavity walls where distress occurred due to design and construction deficiencies*

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# *CHAPTER 2*

# *CAVITY WALL AND VENEER WALL SYSTEMS*

## *2.1 GENERAL DESCRIPTION AND DEFINITIONS*

Both masonry cavity and masonry veneer wall systems have an outer wythe of brick or other unit masonry material separated from an inner wythe or a backup wall by an unfilled vertical space or cavity. It is often difficult to distinguish between these two types of wall systems either by appearance or behaviour. Although the terms are often used interchangeably, their differences should be understood. Specifically, a veneer wall is a non-loadbearing facing attached to a structural backing or *backup* but not relied upon to act with the structural backing in resisting lateral and vertical loads. In cavity wall construction, the wythes are relied upon to act together in resisting lateral loads and possibly also in resisting vertical loads.[1]

Whereas veneers are not assigned the design function of carrying lateral or vertical loads, the stiffness and support conditions often result in their participating in carrying such loads. Implications of such unintended loadsharing will be discussed later with respect to SS backup.

The four types of backup in common construction use in Canada are:

- concrete block masonry, either loadbearing or non-loadbearing;
- steel stud, either axial loadbearing or non-axial loadbearing;
- concrete; and
- timber stud.

Since in Canadian high-rise residential construction the non-loadbearing backup systems of concrete masonry and steel stud are by far the most extensively used forms of construction, this document will focus only on their relevant design, construction, and maintenance issues.

The veneer is typically supported at each floor level by a steel shelf angle or reinforced concrete slab. In the case of a steel structural frame, steel shelf plates may occasionally be used.

Summarizing, this Advisory Document will deal with design, construction and maintenance issues pertaining to brick veneer vertically supported on a steel shelf angle or reinforced concrete slab and laterally supported by non-loadbearing concrete masonry (CM) backup or steel stud (SS) backup.

Both backup systems have advantages and disadvantages which are summarized in Table 2.1.

*TABLE 2.1 ADVANTAGES AND DISADVANTAGES OF CM AND SS BACKUP WALLS*

### CM BACKUP

| *Advantages* | *Disadvantages* |
|---|---|
| • satisfactory performance over many years | • large self-weight |
| • large stiffness which ensures that the veneer does not crack because of a lateral load from wind and earthquake | • details of construction for lateral tie-in with the structure are required |
|  | • significant floor space requirement |
| • continuous wall system for support of insulation, air/vapour vapour barriers, and interior finishes | • installation of electrical and other services within CM wall are complex and difficult to adapt to changing requirements |
| • few parts subject to corrosion or other deterioration | • inherent stiffness requires side gaps to accommodate inter-storey drift of structure |

### SS BACKUP

| *Advantages* | *Disadvantages* |
|---|---|
| • low self-weight | • limited long-term performance history |
| • construction relatively independent of weather conditions | • relatively flexible for support of stiff veneer, leading to potential veneer cracking |
| • relatively small floor space requirement | • detailed design required for numerous components and connections |
| • electrical and other services easily accommodated and modified within SS wall | • requirements for frequent inspection because construction details become quickly hidden |
| • easy insulation placement within SS wall | • metal components, particularly connections for ties, may be susceptible to corrosion |

## 2.2 VENEER WALL REQUIREMENTS

In common with other forms of exterior wall construction, veneer walls must fulfill basic requirements pertaining to

- aesthetics
- durability
- air barrier
- vapour barrier
- fire resistance
- acoustic barrier
- thermal resistance
- structural strength and stiffness.

Single-leaf masonry is seldom completely impervious to driving rain, but a veneer with suitable openings acts somewhat as an open rain screen which reduces the amount of water penetrating the outer layer. Figure 2.1 illustrates this rain screen principle. If the outside pressure and cavity pressure are equalized, there is little tendency for rain to reach the cavity and the so-called open rain screen principle comes into effect. While in typical veneer wall construction the presence of weep holes and vents achieves a measure of pressure equalization, wind-driven rain must be expected to permeate the exterior wythe as shown in Figure 2.1. Flashing and weep holes at the bottom of a wall section then drain such moisture towards the exterior.

Many components contribute to the successful performance of a veneer wall. The various components and their functions are discussed in the following section.

## 2.3 FUNCTIONS OF VENEER WALL COMPONENTS

Components of the two veneer wall systems are shown in Figures 2.2 and 2.3. A brief description of the functions of these components follows.

### *VENEER*

Being the outermost element in the veneer wall system, the veneer protects the inner components from rain, snow, solar radiation, and wind. In a minor way it also contributes to the total insulation of the wall system. The appearance of the building depends largely on the colour, texture, pattern, and durability of the veneer.

### *CAVITY*

The cavity behind the veneer helps achieve an equalization of air pressure across the veneer and thus reduces leakage of water through the veneer. Moreover, the water which does penetrate the veneer is largely prevented from reaching the backup by draining down the cavity to flashings and weep holes which direct it to the exterior.

### *BACKUP*

The principal function of the backup is to resist lateral loads. Non-loadbearing SS and CM backups are never intended to support vertical loads. The backup also supports insulation, air and vapour barriers, and interior finish.

### *TIES*

Ties provide lateral support to the usually slender veneer to prevent it from cracking extensively and possibly collapsing by transmitting lateral loads to the backup. While ties must be axially stiff, they should be flexible enough in bending to permit differential movements between veneer and backup.

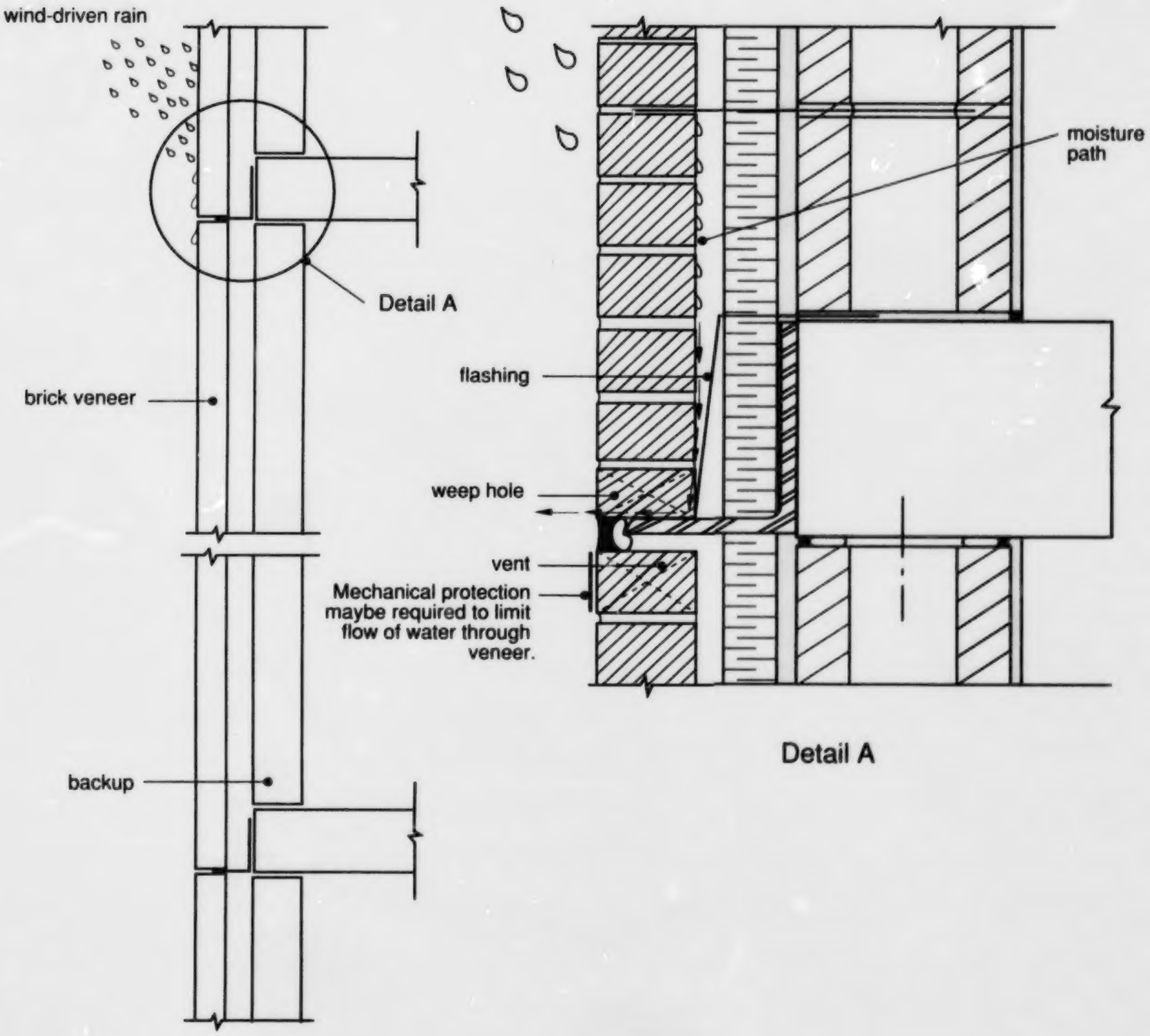

wind-driven rain
Detail A
brick veneer
backup
moisture path
flashing
weep hole
vent
Mechanical protection maybe required to limit flow of water through veneer.
Detail A

Figure 2.1 Open rain screen principle

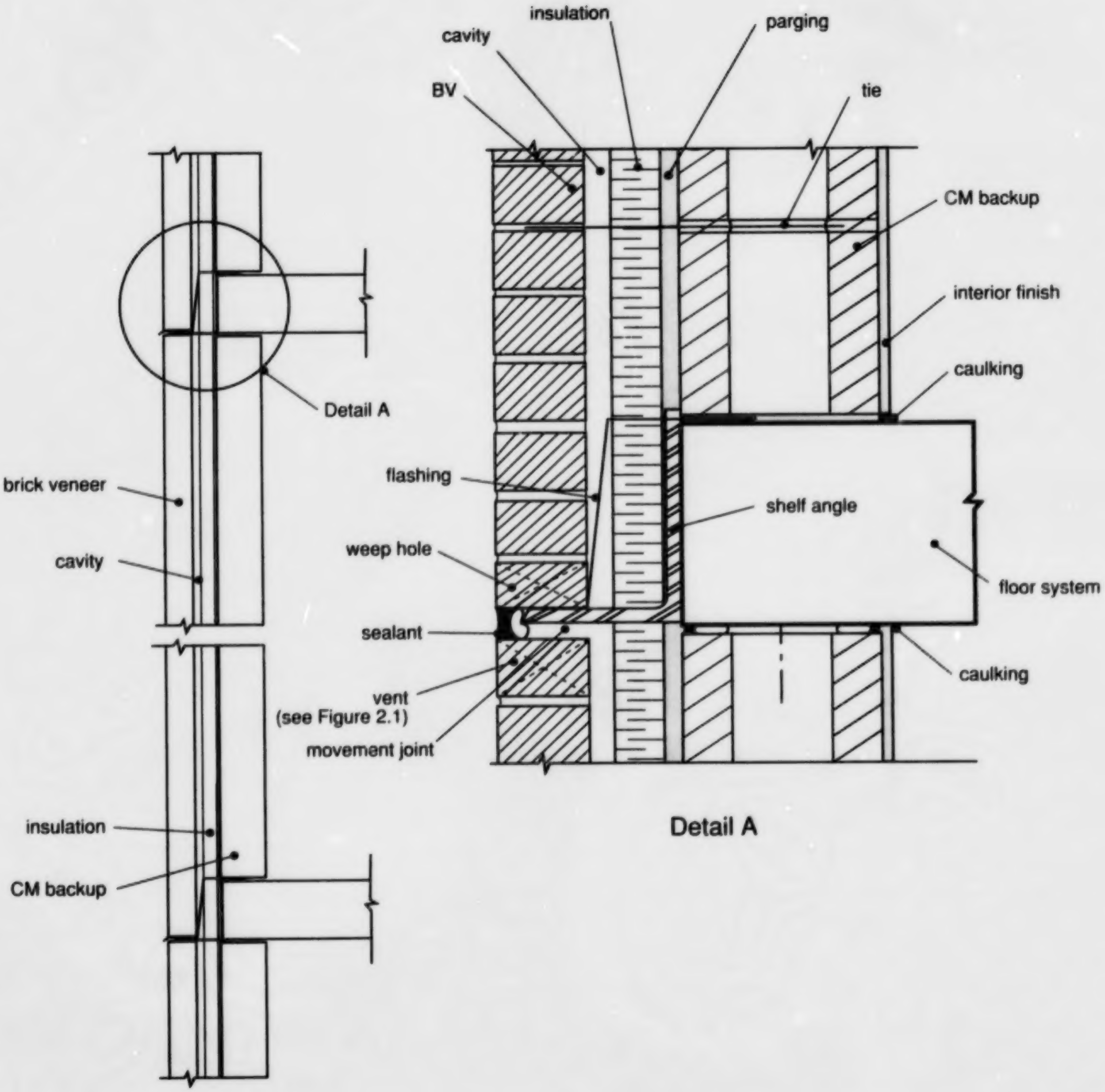

insulation
cavity
parging
BV
tie
CM backup
interior finish
caulking
Detail A
flashing
shelf angle
brick veneer
weep hole
cavity
floor system
sealant
caulking
vent
(see Figure 2.1)
movement joint
Detail A
insulation
CM backup

Figure 2.2 BV/CM wall system components

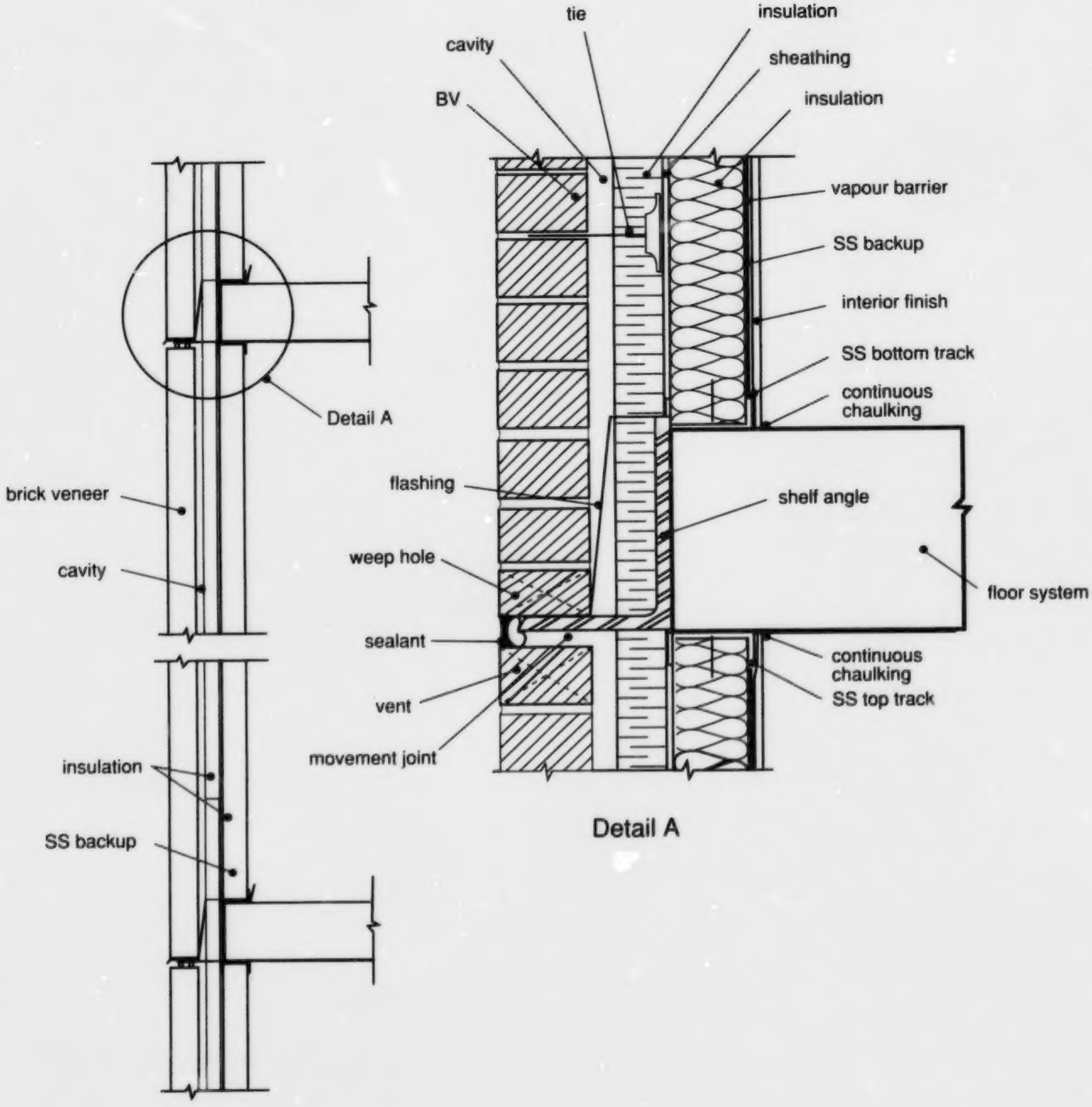

Detail A
brick veneer
cavity
insulation
SS backup
tie
insulation
cavity
sheathing
BV
insulation
vapour barrier
SS backup
interior finish
SS bottom track
continuous chaulking
flashing
shelf angle
weep hole
floor system
sealant
continuous chaulking
vent
SS top track
movement joint
Detail A

Figure 2.3 BV/SS wall system components

### *INSULATION*

Insulation is the most important single component in resisting heat flow across the wall system and thus reducing heating and cooling costs. Insulation may be located on the interior side of the backup, within the backup system or within the cavity on the exterior side of the backup. Combinations of these placements are possible.

### *VAPOUR BARRIER*

The function of the vapour barrier is to retard the diffusion of vapour through the wall, usually from the inside towards the outside. A vapour barrier controls condensation within the wall system due to diffusion.

### *AIR BARRIER*

The air barrier reduces both inward (infiltration) and outward (exfiltration) air leakage through cracks, gaps, and holes inevitably present in the backup wall system. This, in turn, reduces both heat loss and potential condensation of moisture present in exfiltrating air within the wall.

### *SUPPORT SYSTEM*

Two support systems are encountered, one for the veneer, the other for the backup.

The support under the veneer is usually a steel shelf angle securely attached to the edge of floor slabs. Alternatively, floor slabs may project through the entire wall assembly to carry the veneer directly. The main function of the veneer support is to carry the weight of the veneer.

The main function of the supports pertaining to the backup is to carry its own weight and to transmit lateral loads on the backup to the structural frame. Backup support details for both SS backup and non-loadbearing CM must allow the floor slab above the backup to deflect freely without introducing compressive loads into the backup.

### *FLASHING*

Moisture can accumulate in the cavity either by leakage through the veneer from the outside or by condensation from exfiltrating air. The function of flashing is to drain out this water and thereby protect any moisture-sensitive components behind the cavity.

### *WEEP HOLES AND VENTS*

Weep holes and vents are small intentional openings, usually in the form of unfilled head joints in masonry veneers. These openings can also be provided by using inserts of plastic, metal, or other material. Tee vents or other devices can provide mechanical protection for weep holes and vents. Weep holes are usually located in the bottom course of the veneer right above the flashing to drain water out of the cavity. Vents located near the top of the wall allow air circulation to reduce moisture levels in the cavity and surrounding materials. Both weep holes and vents help in the pressure equalization across the veneer.

### *MOVEMENT JOINTS*

Two horizontal movement joints are typically encountered. The first is a movement joint between the top course of the veneer and the underside of the veneer support. This joint permits any differential movement between veneer and structure to take place without an undesirable build-up of veneer stresses. The second horizontal movement joint must be provided between the backup and the underside of the floor slab. Whether the backup is concrete masonry or steel stud, the joint is typically provided at the top of the backup. This joint prevents build-up of stresses in the backup as the structure shortens and beams or slabs deflect slightly with time because of various deformations.

Vertical movement joints provided in long veneers and at critical veneer locations reduce unsightly and potentially harmful cracking in the veneer. Movement joints in the veneer are also required near windows and other openings and at any substantial change in cross-sectioned area to accommodate differential movements between veneer and backup without causing distress in window and door frames.

### *JOINT SEALANTS*

Joint sealants are used in exterior movement joints to control ingress of moisture, dirt, and grit. They are also used in movement joints pertaining to the backup to minimize exfiltration. Sealants must be capable of deforming repeatedly without failure over long periods.

## 2.4 *SUMMARY*

For satisfactory long-term performance of the BV/CM and BV/SS systems, careful attention must be paid to the design, construction, and maintenance of the veneer wall components. Parts 2 to 4 of this publication deal with the design, construction, and maintenance requirements.

## REFERENCE

Canadian Standards Association, CAN3-S304-M84 *Masonry Design for Buildings*, CSA, Rexdale, 1984, 69 pages.

[redacted]

# PART 2 STRUCTURAL CONSIDERATIONS

## CHAPTER 3

## GENERAL DISCUSSION OF STRUCTURAL REQUIREMENTS

### 3.1 INTRODUCTION

Although design and construction of BV wall systems are two distinct phases of the building process, designers must recognize the factors affecting the quality of construction.

### ROLE OF THE DESIGNER

The design should not place unreasonable demands on construction workers beyond normal standards for good-quality construction. Additionally, requirements for new construction skills and unusual methods or sequences of construction should be avoided so that construction can proceed in an organized and efficient manner.

Regardless of the use of new concepts or methods of construction, designers must recognize that there are important structural requirements for any wall system and that in fact past practices may not be adequate. In addition to the basic structural considerations, both the details of the design and the eventual choice of contractor should take into account

- existing and required training of the workforce;
- quality and availability of supervision;
- frequency and effectiveness of inspection;
- interaction with the main structure;
- interaction with the building science aspects of design; and
- special requirements for plans, specifications, and shop drawings.

### ROLE OF THE CONTRACTOR

While contractors and construction workers can be told explicitly what is expected of them, compliance with the specifications is more likely if they understand the purposes of certain construction details and the consequences of improper construction.

Whereas, for example, they do not need to know flexural-torsional buckling theory, they do need an understanding that failure to properly connect internal bridging to the steel studs will allow the studs to twist and fail at a much lower load. Alternatively, for CM backup walls, building in of the wall tight to the structure can drastically alter the behaviour of the building under lateral loads and, if not designed for, result in premature structural failure. Therefore, it is necessary that contractors have knowledgeable employees, especially at the supervisory level. Also, the development of a better and more consistent quality of construction would be aided both by greater consistency in design and detailing and by the development of accepted standard practices.

Since design and construction are so closely linked, both are presented together in this Advisory Document. However, drawings and the notes attached to them have been organized so that it is possible to concentrate on the construction aspects without repeatedly having to go through the associated background and theory.

### 3.2 GENERAL DESIGN AND CONSTRUCTION REQUIREMENTS

The structural design of BV wall systems should satisfy the following general requirements:

- adequate strength to resist design loads;
- adequate stiffness to assure serviceability under normal conditions;
- adequate durability, including compatibility of materials;
- adequate robustness not to be adversely affected by normal construction and use conditions;
- adequate redundancy and toughness to withstand damage without completely collapsing;

- adequate detailing of the components of the wall system and the interconnections between them to assure that the wall performs as intended; and
- integration with both the behaviour of the supporting structure and the building science requirements for the wall system.

These considerations, as they generally apply to brick veneer wall systems, are discussed in the following sections.

## 3.3 *STRENGTH*

As is illustrated in Figure 3.1, the backup wall system for brick veneer must be designed not only to carry its own weight in the vertical direction but also to resist out-of-plane lateral load due to wind, earthquake, and general occupancy and use. Normally the veneer and backup walls are designed with movement joints which allow relative vertical and horizontal movement of the structure without transferring an in-plane load to either the backup wall or the veneer.

As will be discussed in more detail later, the structural requirements for the veneer itself are less well defined since, by definition, the backup wall is designed for the entire lateral load. However, serviceability and interaction with building-science-related performance can be used to help define strength criteria for the BV where cracking may be considered a type of failure. As is shown in Figure 3.2, prior to cracking of BV, the share of the lateral load resisted by the BV is much greater where the backup is relatively flexible, which is typically the case for SS backup walls.[1,2,3,4,5]

Ties and anchors must transfer the lateral load from the brick veneer to the backup wall and to the main structure. Also, in some cases, there are secondary requirements, such as for attachment of exterior insulation to resist suction forces. These features of the design will be covered in Chapters 6 and 7.

Specific aspects of loading as applied to BV wall systems are discussed briefly.

### *WIND LOADING*

Wind pressure normal to the wall most frequently controls its design. As is set out in the National Building Code, [6] the design pressure for cladding depends on geographic location, exposure, and internal pressure conditions.

Regarding the latter, breakage of windows and failure of doors or vents during high winds will cause internal pressures in the building which should be added to the corresponding positive or negative external wind pressures.

For wind loads, the National Building Code of Canada provides a full treatment of pressure distributions over the faces of buildings and the effects of wind gust and exposure conditions on both internal and external wind pressures. However, although internal pressures are always resisted directly by the backup wall because the air barrier is located at this position, the location of application of external pressure is not always clear.

Theoretically, the use of the veneer as an open rain screen implies that airflow through vents and weep holes results in the cavity having the same air pressure as the outside surface of the veneer. If such is the case, as is shown in Figure 3.3, the veneer is in equilibrium and the backup wall has the entire load applied to it. However, even in this case, the stiffness or resistance of the veneer to bending will result in part of the wind load being transferred back to the veneer by the ties as indicated in Figure 3.4[7,8] for a flexible backup wall. As mentioned previously, the distribution of load between the veneer and the backup depends on the relative stiffness of the veneer and backup wall and on tie stiffness.[9,10,11] If ties are very stiff, then the veneer will have nearly the same deflection profile as the backup.

In actual fact, full pressure equalization across the veneer may not be achieved because:

- air leakage through the backup wall reduces pressure equalization of the cavity and the exterior;
- an insufficient volume of air can be moved through openings in the veneer to equalize short-term pressure changes due to wind gusts;
- as illustrated in Figure 3.5, movement of air in the cavity to areas of unbalanced pressure, that is, sidewalls compared with windward walls, may make it impossible to move a sufficient volume of air through vents and weep holes;
- pressure differences over the face of the wall mean that cavity pressure will differ from external pressures over most of the wall area;
- vents and weep holes are omitted, partially plugged or simply too small to transmit sufficient air for cavity pressure equalization; and
- for short-term pressure changes, deflection of the backup wall can reduce cavity pressure.

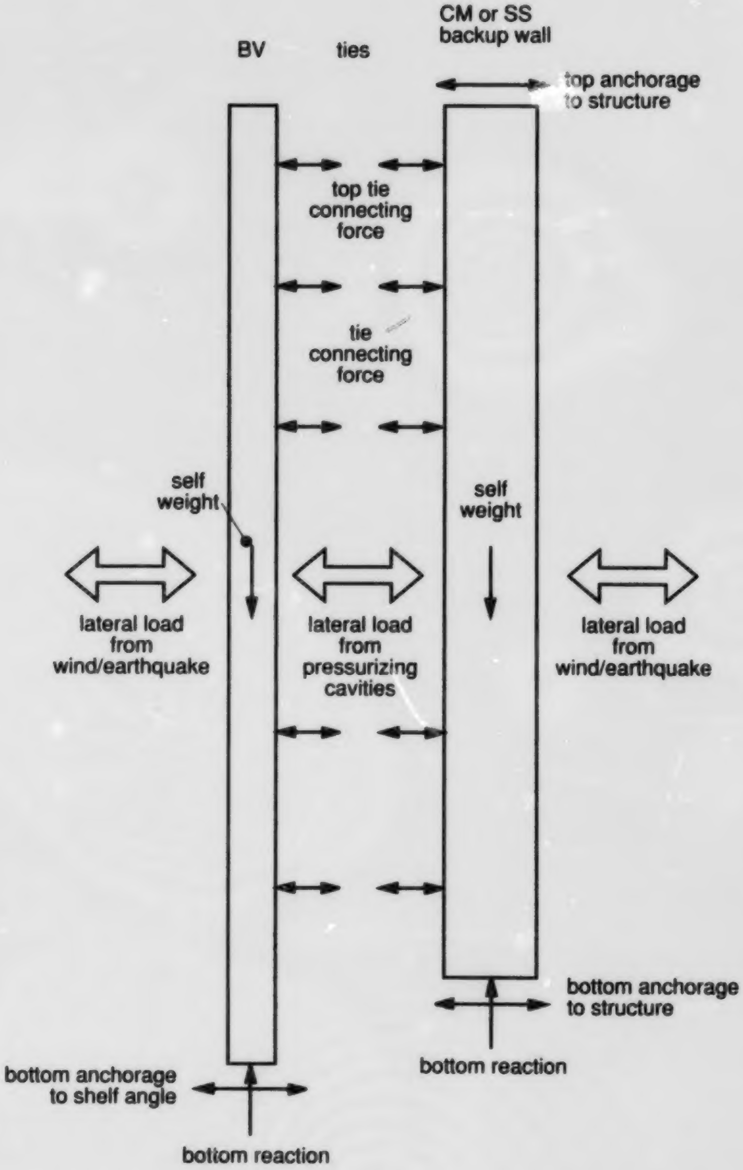

CM or SS backup wall
BV
ties
top anchorage to structure
top tie connecting force
tie connecting force
self weight
self weight
lateral load from wind/earthquake
lateral load from pressurizing cavities
lateral load from wind/earthquake
bottom anchorage to structure
bottom reaction
bottom anchorage to shelf angle
bottom reaction

Figure 3.1 Schematic drawing of forces on BV wall systems

In the extreme, nearly the full force of the external pressure may be transmitted by the veneer. Although analyses indicate that this is the most critical loading case for maximum tie forces and bending moments in the veneer, variations in the relative stiffnesses of the walls and the tie stiffnesses and locations can result in significant changes in these internal forces.

## *SEISMIC LOADING*

In seismically active areas and particularly where relatively massive walls are used, out-of-plane forces proportional to the mass of the wall can control design. This loading can be especially critical for connections to exterior wall elements where the horizontal force factor, Sp, is 11 in the NBC, 1985.

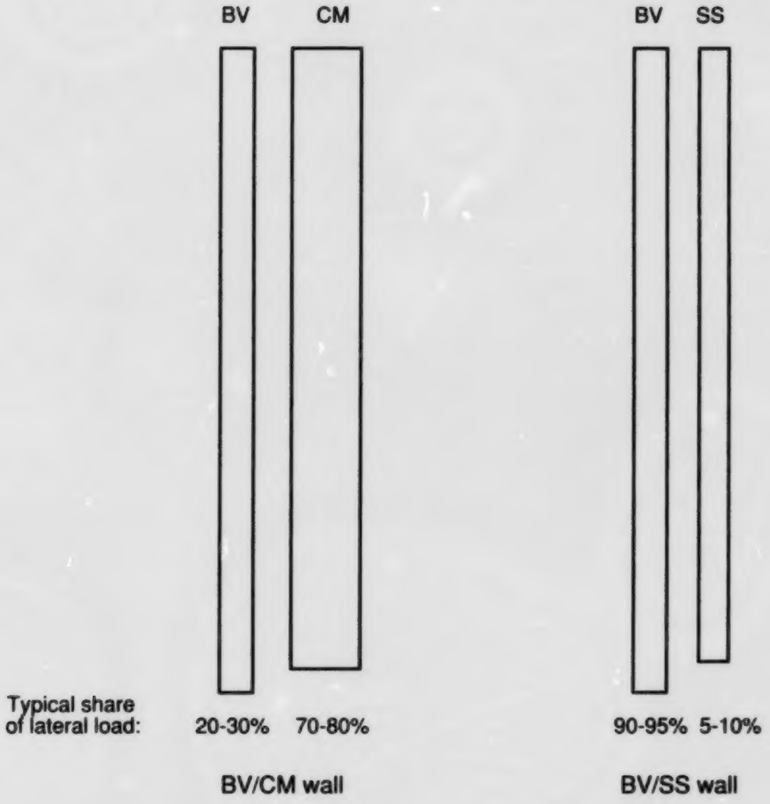


Figure 3.2 Typical load-sharing between BV and backup walls for uncracked BV

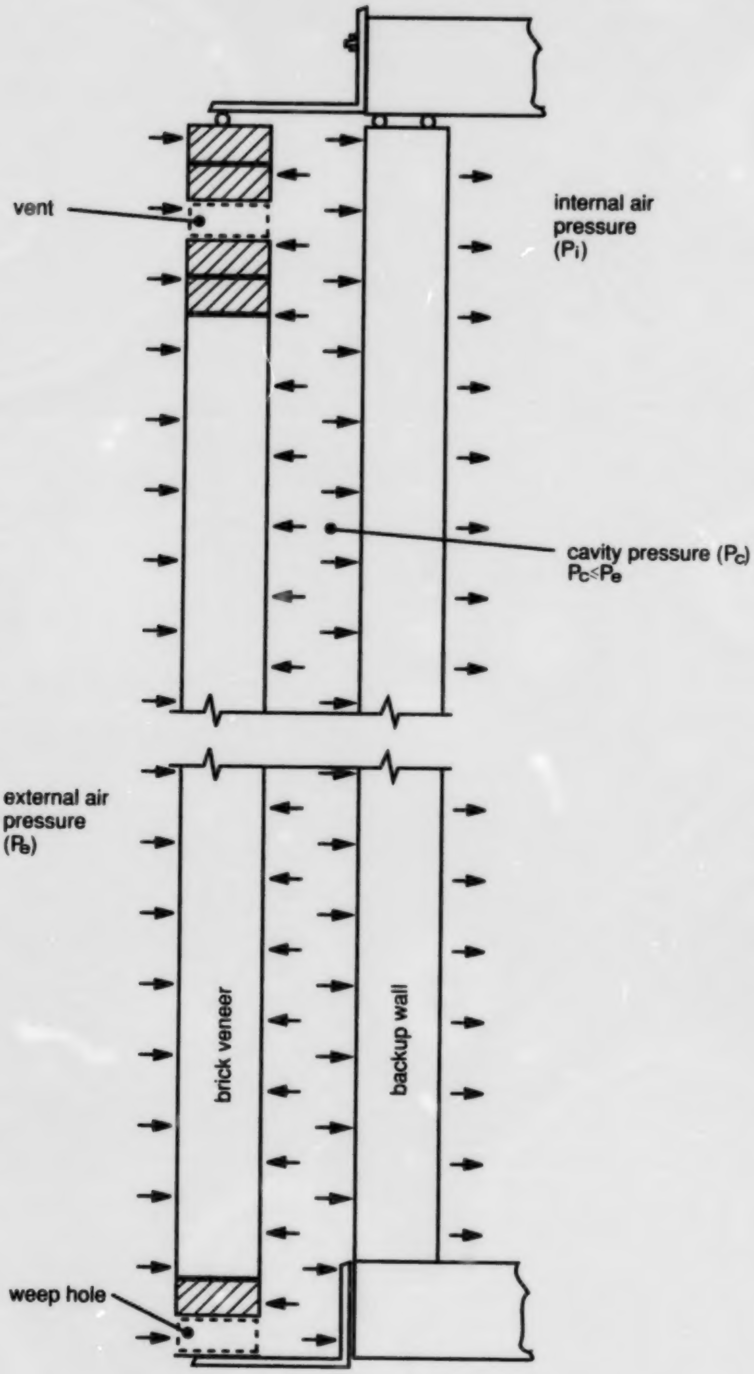

vent
internal air pressure ($P_i$)
cavity pressure ($P_c$)
$P_c \leq P_e$
external air pressure ($P_e$)
brick veneer
backup wall
weep hole

**Figure 3.3** Distribution of wind load to brick veneer and backup wall for pressurized cavity case

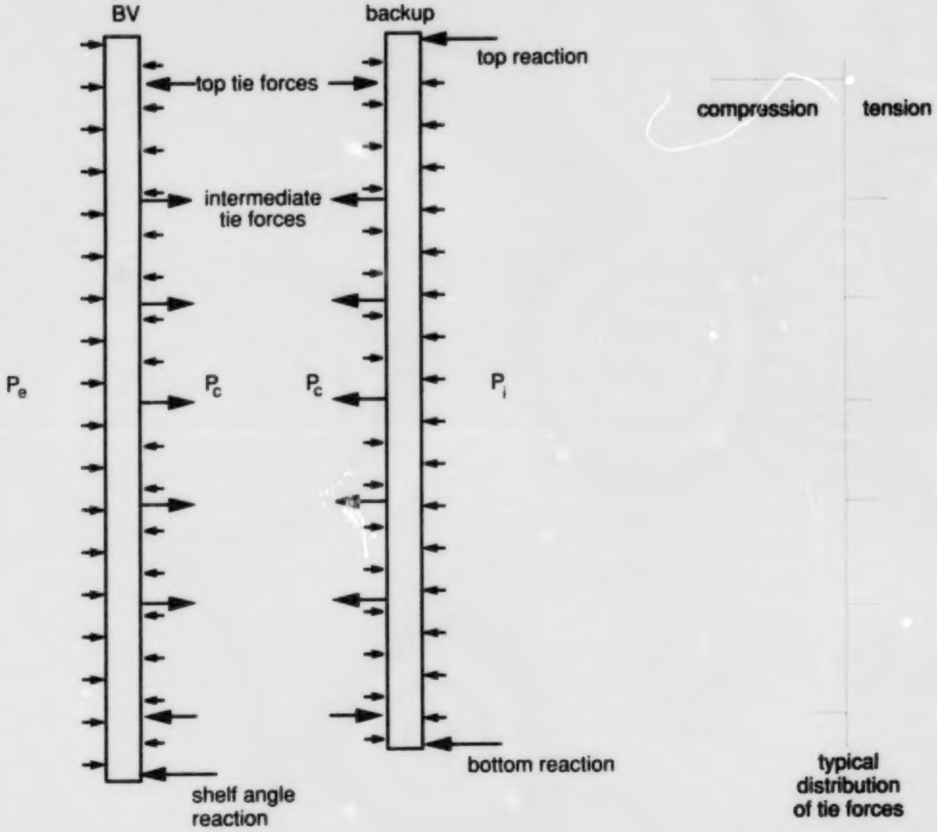

BV
backup
top tie forces
top reaction
compression
tension
intermediate tie forces
$P_e$
$P_c$
$P_c$
$P_i$
shelf angle reaction
bottom reaction
typical distribution of tie forces

Figure 3.4 Redistribution of load back to BV through tie forces

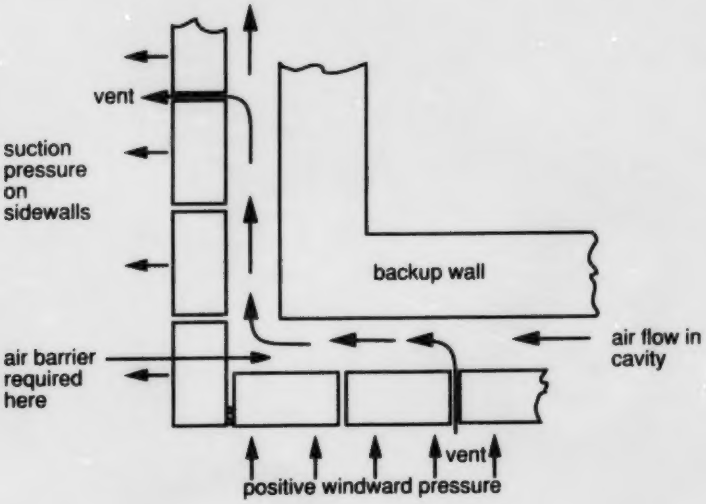

vent
suction pressure on sidewalls
backup wall
air barrier required here
air flow in cavity
vent
positive windward pressure

Figure 3.5 Lack of pressure equalization in cavity due to air movement

Depending on the value of the zonal velocity ratio, v, and the weight of the wall, Wp, the lateral force, Vp = v Sp Wp, can be quite large. Figure 3.6 contains a sketch and calculations illustrating this effect for a 3-m high brick veneer. In addition to the strength approach to the design of the brick veneer wall systems for earthquake forces, good engineering design practice should include some consideration of performance under damaged conditions and general resistance to complete collapse.

### *OTHER LOADING*

Wall loads associated with occupancy normally do not affect the overall structural design. However, unusually heavy loads cantilevered off the wall or the potential for impact loading may require special consideration for some situations.

## *3.4 SERVICEABILITY*

Serviceability requirements for structural design are very much related to the many building science aspects of design discussed in Chapter 8. However, clear definition of acceptable criteria either explicitly or through arbitrary limits are generally lacking. An example is the degree to which cracking of the brick veneer can be permitted.

Generally, the structural stiffness is the main link with serviceability aspects where deflection, vibration, and other movement have their own limits and also may possibly affect the interaction and integrity of the wall components.

Although the working stress approach to masonry design has been assumed to assure adequate serviceability performance under unfactored loads, integration of masonry (brick veneer) with other structural systems (steel studs) has focused attention on the need to establish reasonable serviceability criteria. Specifically, it has been shown that, although brick veneer may leak because of rain, cracked brick veneer permits much greater rain leakage.[12,13] The amount of leakage increases with increasing crack widths.

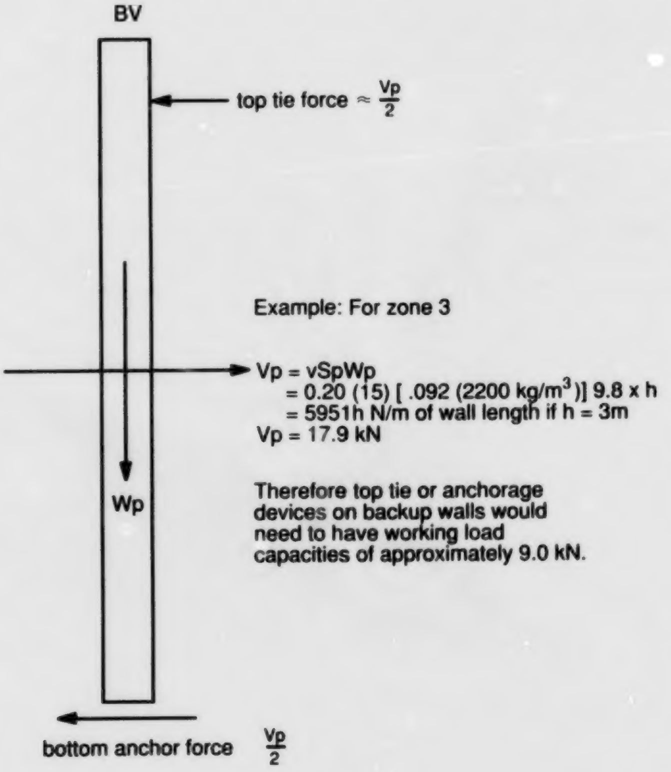
Since brick veneer supported by a stiffer backup wall (concrete masonry) may also crack because of causes other than lateral load, the magnitude and potential consequences of rain leakage become a matter of probability. At the present time, however, there is not sufficient information to carry out a probability analysis. Therefore, by necessity, the recommendations for CM and for SS backup walls are a somewhat arbitrary attempt to provide a rational way of incorporating this consideration in the design.

## *3.5 DURABILITY*

A key feature of structural design is to assure that the *as constructed* components will retain characteristics reasonably close to their original properties. This means initial strengths and stiffnesses should not deteriorate over the life of the structure, otherwise design provisions must take into account anticipated changes.

Example effects that should be considered include fatigue or repeated loading, general loosening of components, corrosion, freeze-thaw damage, and wetting. In addition to assessing the potential influence of these types of changes on structural behaviour, their interactions with building science design requirements are also important and will be discussed in Chapter 8.

For such aspects as corrosion, it should be recognized that climatic and geographic factors can lead to large differences in the potential for corrosion. In industrial areas, rain may be slightly acidic, whereas in some geographic locations, such as along the east coast, salt-laden rain is frequently driven by high winds, a situation which aggravates leakage. Also there is recent evidence that walls adjacent to highways experience increasing salt contents from airborne salt spray. Consideration of such factors along with the intended or likely life of the structure may show that to allow gradual deterioration is not acceptable and in this example the use of non-corroding rather than corrosion-resistant system components, such as ties, may be essential to assure the long-term safety of the wall system.


BV
top tie force ≈ $\frac{Vp}{2}$
Wp
bottom anchor force $\frac{Vp}{2}$

Example: For zone 3

Vp = vSpWp
= 0.20 (15) [ .092 (2200 kg/m$^3$)] 9.8 x h
= 5951h N/m of wall length if h = 3m
Vp = 17.9 kN

Therefore top tie or anchorage devices on backup walls would need to have working load capacities of approximately 9.0 kN.

Figure 3.6 Example calculation of connector forces for earthquake loading

Quite often, special attention to a particular detail or improvement in a specific component is all that is required to gain a significant increase in the satisfactory life of the wall system. Conversely, costs for repair or replacement of deteriorated components are usually extremely disproportionate to the increment of cost required for an initially more durable design.

## *3.6 ROBUSTNESS AND REDUNDANCY*

The structural design of the wall components should incorporate construction methods which are relatively simple and therefore lend themselves to proper construction in the field. The design should incorporate a robustness which will ensure that normal construction practices and normal use will not damage any components or significantly reduce their ability to perform the intended functions. In addition, good design will incorporate a toughness and degree of redundancy which enable the wall system to withstand damage without completely collapsing.

The creation of toughness or redundancy in a design involves ensuring that failure of a single component will not result in collapse. Some degree of ductility or alternate load paths can usually be incorporated at minimal cost – often at no cost at all. Examples of robustness and redundancy are shown in Figure 3.7.

## *3.7 IMPORTANCE OF DETAILS*

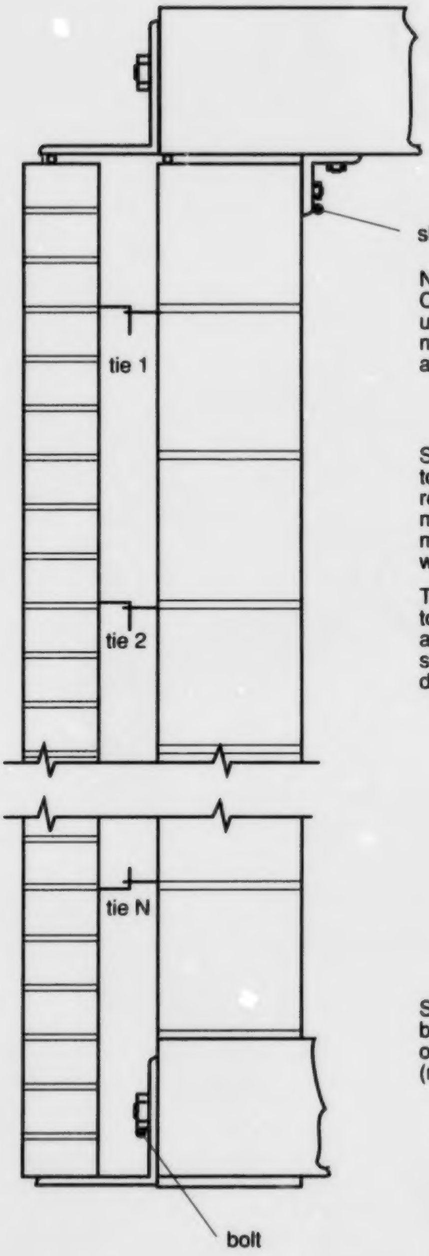
Structural detailing is singled out for special mention because the ability of a design to satisfy the structural requirements is often at least as dependent on the method of connecting, joining, or otherwise supporting components of the design as it is on the design of the components themselves. For example, as will be discussed later, the shelf angle support for veneer may be structurally adequate but totally ineffective, unless the details properly address the special needs for movement and adjustability.

Thus details should be clearly thought out in terms of all the related functions. They should be clearly drawn and described in the specifications, and they should be sufficiently simple to achieve compliance during construction.

## *3.8 APPROVALS*

A variety of materials and components are used in veneer wall construction involving either CM or SS backups. Frequently materials, such as ties and anchors, are substituted on the basis of apparent equivalence either because of the unavailability of the originally specified materials or because of cost reduction. It is essential that such substitutions be approved by the designer.

Too often SS backup systems are merely adopted from manufacturer's literature and treated in much the same way as interior steel stud partitions. Adoptions from trade literature must be verified and approved by the designer to ensure structural adequacy of the backup and ties. Any modifications of the original details deemed necessary during the construction phase must also be approved by the designer.



Whereas tie 1 may be adequate to resist applied loads, inclusion of ties 2 to N provides redundancy which, aside from assuring more uniform distribution of load, reduces the importance and consequences of failure of any individual tie.

Note:
Clip angle detail must allow unrestrained differential movement between the slab and the masonry wall.

Sufficient clip angles must be used to provide a redundant line of reactions. The methods of attachment must withstand repeated loading, movements, and environmental forces without deterioration.

Ties must be sufficiently robust to tolerate handling on the job site and resist damage during installation such as, for instance, where coursing does not match.

In a situation where damaged veneer may tend to fall away from the building, ties 1 and 2 provide a certain toughness by retaining load-resisting capacity, whereas tie N would tend to disengage and not add toughness to the construction. A tie that cannot disengage, even under extreme displacement, would be preferable.

Shelf angle segments anchored only by two bolts do not represent redundancy or toughness. A three-bolt arrangement (minimum) would provide both effects.

Figure 3.7 Examples of robustness and redundancy

## 3.9 SHOP DRAWINGS, SAMPLES AND CALCULATIONS

SS backup construction requires the production of shop drawings.[14] Similarly, anchors, joints, and openings in CM backup must be detailed. These drawings should include all necessary details for assemblage and erection, including installation of windows and other attachments. The designer responsible for preparing the shop drawings should normally carry out the inspection (see Section 3.11).

### *CM BACKUP*

While there is considerable experience with use of CM backup walls, this familiarity does not lessen the need for design calculations, drawings, and supervision. Poor performance of the backup and in some cases severe damage to the structure has resulted from lack of attention to design and detailing. Provision of movement joints, checks to assure that the supporting beam/slab is sufficiently stiff, allowance for openings, and selection of ties and anchors are some of the specific items requiring attention.

Perhaps because the structural significance of backup walls has been underrated, there has been a tendency to adopt standard designs either taken from past practice or proportioned in accordance with the empirical provisions of either Chapter 6 of CSA Standard CAN3-S304-M84[15] or Part 9 of the NBC.[16] Designers must recognize that there are specified limitations for the use of these provisions and that full engineering calculations are often required. This topic is discussed in more detail in Chapter 6.

### *SS BACKUP*

For SS construction, details of connection and anchorage, bracing and bridging, splicing, and door/window openings must be provided.

All member sizes and thicknesses, fastener sizes, and various dimensions including tolerances should be clearly shown. Design loads should also be shown on panel diagrams. The CSSBI publication, *Lightweight Steel Framing Manual* (CSSBI 50M-1987),[17] contains more extensive information on the subject of drawings and details.

A large number and variety of materials and components may be involved in BV/SS construction. It is important that representative samples of the materials involved, including fasteners and screws, be submitted to the designer for review and reference purposes.

If design of the SS backup system is not carried out by the project architect/ engineer, the shop drawings from the contractor should be accompanied by engineering calculations and other data to facilitate verification of the adequacy of the system. These aspects are reviewed in more detail in Chapter 7.

## *3.10 MATERIALS HANDLING AND STORAGE*

Specifications and job planning should make provision for storage and protection of materials on site. Where a manufactured component, such as mortar, is made on site, protection of the component materials and the combined material from detrimental weather conditions is required. Similarly provisions for handling manufactured materials should minimize damage.

All masonry materials at the construction site, such as masonry units, sand, lime, and cement should be protected against wetting before use by storing them on elevated platforms and covering them with waterproof sheet material. In winter, sand should be so stockpiled so that heating is possible if necessary. Steel reinforcement, ties and anchors should be kept free of oil, dirt, and heavy rust which may impair bond. Ties should be handled with care so that no mechanical damage occurs.

Steel studs should be stored indoors in their wrappings or containers until ready for use. Because of relatively thin sections, the studs can be easily bent, dented, or twisted; care in handling is therefore necessary. If the panels are first assembled on the floor, it may be necessary to lift the assemblage at two or more points depending on the length of the panel.

## *3.11 INSPECTION*

Experience has shown that it is normally best practice for the designer to be responsible for the inspection of the brick veneer wall system. As part of the design process, designers should keep in mind the ability to inspect. Responsibility for inspection should be clearly set out in the contract documents. Where a person other than the designer is assigned this responsibility, knowledgeable and proven experience with this type of construction is essential.

The specifications or other contract documents must clearly set out schedules for inspection and requirements for the contractor to provide notice of completion of specific parts of the construction before proceeding to close in or otherwise cover completed work. Schedules should be related to specified stages of the work rather than at stated time intervals. Too often either random or fixed times for inspection are ineffective means of quality assurance.

## *3.12 SUMMARY*

This chapter provides the general introduction to structural design of BV wall systems introduced in Part 2 of this Advisory Document. Chapter 4 is devoted entirely to the requirements for design of movement joints to emphasize their importance. Lack of proper attention to this aspect of design has caused severe distress in many existing buildings. This has resulted in some unsafe conditions and eventually great costs to the owners for remedial work.

Design aspects common to the structural components of all BV wall systems are presented in Chapter 5, whereas Chapters 6 and 7 are devoted to features specifically pertaining to CM or SS backup respectively. Since interaction between structural and building science performance is unavoidable, reference is made where possible to the appropriate sections of Part 3.

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[15] Canadian Standards Association, CAN3-S304-M84, *Masonry Design for Buildings*, CSA, Rexdale, 1984, 69 pages.

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# CHAPTER 4

# MOVEMENT JOINTS

## 4.1 GENERAL

A variety of materials are used in the construction of veneer wall systems and the main structure. These materials, such as brick masonry, concrete block masonry, concrete, and steel, exhibit different deformation characteristics both under load and under changes in thermal and moisture conditions. Moreover, the various components of the veneer wall system and main structure are subjected to different loading, thermal, and moisture conditions. Resultant differential movements can lead to cracking, spalling, and collapse of veneer panels, unless movement joints are provided at strategic locations to control potential buildup of stresses.

Both clay brick and concrete brick are used in veneer construction. However, since differential movements between veneer and structure are larger and therefore more critical for clay brick mainly due to moisture expansion of the clay brick, the following discussions about movement joint deal with veneer built of clay brick masonry. (It should be noted that concrete brick veneer can experience shrinkage-cracking especially where there are no contraction joints.)

## 4.2 MATERIAL DEFORMATIONS AND BUILDING MOVEMENTS

The following paragraphs deal with key material deformations and associated building movements.

### ELASTIC DEFORMATION

Any loaded material will shorten or lengthen depending on whether it is in compression or tension. When initially loaded, the deformation is nearly proportional to the load and is then known as elastic deformation. Concrete, with a strength of 20 MPa, for example, loaded in compression to a stress of 8 MPa, will shorten about 0.4 mm/m (0.04 percent).

Steel, being stiffer, would require 10 times as much stress to give the same strain, but since it is normally stressed to a higher level, the deformation will be of about the same order.

### LONG-TERM DEFORMATION

Under a constant load, some materials undergo further deformation with time in addition to the initial elastic deformation. This additional deformation, called creep, is best described as a sort of plastic flow. Concrete is notable for this; the creep movement typically can be 1.5 to 2 times the elastic deformation. Creep takes place at a decreasing rate with time; most of it occurs within 2 to 3 years. Steel does not creep significantly at service load levels.

### MOISTURE MOVEMENTS

Most porous building materials will absorb moisture when in contact with water, or from the air, if the temperature of the material is below the condensation (dew) point corresponding to the relative humidity of the ambient air. Reversal of the conditions results in drying out.

Concrete expands or contracts as its moisture content changes, but for reasons not explained here, the net long-term effect is drying shrinkage in a normal air environment. Concrete block masonry may shrink 0.3 to 0.6 mm/m (0.03 to 0.06 percent), depending upon the type of mortar, the age of the blocks when the blocks were placed, how they were cured (low-pressure steam or autoclave), how they were stored, and the block materials.

Clay bricks, on the other hand, display a net expansion as they come into moisture equilibrium with the air after firing. Since this requires time, the expansion that takes place in the wall depends partly on the age of the bricks when they were laid. The range of clay brick masonry moisture expansion is not yet well defined for Canadian bricks, but 0.2 mm/m (0.02 percent) is considered an average value.

### *THERMAL MOVEMENTS*

Materials expand with an increase in temperature and contract with a decrease in temperature. In the range of temperatures normally encountered, common building materials exhibit fairly constant rates of dimensional change with changes in temperature. For a change in temperature of 1°C, the dimensional change is about 0.012 mm/m for steel and about 0.011 mm/m for normal-density concrete. The equivalent typical values are 0.010 mm/m for normal-density concrete block masonry, 0.008 mm/m for lightweight concrete block masonry, and 0.006 mm/m for clay brick masonry.

In Canadian climatic conditions, the range of temperature variation in the exterior envelope of a building is wide. A dark-coloured brick masonry veneer facing west-southwest can reach a temperature as high as 65°C in summer; the wintertime temperature in the same veneer may be as low as -25°C or even lower, depending on geographic location. If the temperature during construction is assumed to be 20°C, the veneer temperature may either decrease or increase by about 45°C over the year. The resulting thermal movement in a typical 3.0 m high panel is therefore slightly less than a 1-mm contraction or expansion.

### *TOTAL MOVEMENT IN CLAY BRICK VENEER*

The unrestrained maximum expansion or contraction in a clay brick veneer due to change in temperature and moisture expansion can be estimated by using the following formula:

$$\Delta L = [0.2 + 0.006\,(T_e - T_r)]L$$

(Equation 4.1)

where

$\Delta L$ = total expansion or contraction (negative for contraction), mm

$T_e$ = maximum or minimum temperature, °C

$T_r$ = reference temperature of veneer, °C

$L$ = length of veneer, m.

In the given formula, 0.2 and 0.006 are related to typical clay brick moisture expansion and thermal coefficient values, respectively. In using the formula, the designer must adjust these values if material properties differ significantly from typical values.

It should be noted that the temperature of the veneer, $T_r$, during construction may vary rather widely, depending on the time of year. For example, a 10-m long veneer wall constructed in summer under sunny conditions with its mean temperature, $T_r$, around 40°C will undergo a maximum expansion of about 4 mm under typical extreme temperatures of $T_e$ equal to 65°C in summer and a maximum contraction of about 2 mm at -25°C in winter. On the other hand, the same veneer constructed in winter with its mean temperature, $T_r$, around 5°C will undergo a maximum expansion of about 6 mm and a maximum contraction near zero under the same extreme temperatures.

The values of movements quoted are intended to give an idea of their magnitude. An accurate calculation of building movement would require more detailed information. The changes in length may seem quite small but over long lengths can be sizeable. For example, an unrestrained concrete block wall 30 m long would shorten about 10 mm because of shrinkage. Other movements are of the same order of magnitude. Movements may be additive or take place in opposite directions, partially cancelling out. For example, moisture and temperature movements can be in the same or opposite directions. In general, movements which are restrained or differential movements between connected elements cause problems.

## *4.3 WIDTH OF MOVEMENT JOINTS IN CLAY BRICK VENEER*

The required width of vertical movement joint is primarily governed by the maximum expansion or contraction which can occur in a given segment of veneer as well as by the properties of the sealant and backing material used to make the joint weathertight.[1,2] The maximum expansion or contraction with respect to the position of the veneer during application of sealant is governed by the veneer temperature during sealant application and the time interval between construction and sealant application. By the time sealants are applied, some of the brick moisture expansion has taken place already, but this is discounted in the following example. When the sealant installation temperature is 20°C, the maximum expansion in a 10-m long veneer is 4.7 mm, whereas before moisture expansion, the contraction is 2.7 mm. On the other hand, if sealant is applied when the veneer temperature is 5°C, the maximum expansion is 5.6 mm and the maximum contraction is 1.8 mm before moisture expansion of the brick.

The width of the joint is governed by the arithmetically greater value of expansion or contraction. Therefore, for minimum joint thickness, the sealant ideally should be applied when the veneer temperature is about halfway between the extremes.

Movement capabilities of various sealants available on the market vary widely. In general, the greater the movement capability of sealant, the smaller is the required joint thickness.

The latter can be calculated by the following formula:

$$j = \frac{(\Delta Lmax \times 100)}{d} \qquad \text{(Equation 4.2)}$$

where $j$ = required joint width at the temperature of sealant installation, mm

$\Delta Lmax$ = arithmetically greater value of the unrestrained maximum expansion and contraction of the veneer segment for the temperature of sealant installation, mm

$d$ = cyclic deformability of sealant in percent.

Widely used sealants for masonry applications are silicones and polyurethanes having a cyclic deformability of about ±25 percent. If such a sealant is to be applied when the veneer temperature is 20°C, the required width of movement joints spaced at 10 m is about 19 mm. However, if the veneer temperature is 5°C during application of sealant, a 22 mm joint would be required.

The joint width determined according to Equation 4.2 is based on unrestrained movements. In practice, veneer movements cannot occur completely unrestrained because some resistance to movement is provided by supports, ties, and other details. In addition, as mentioned previously, some movements will have occurred before sealant installation. This means the above joint widths are upper-bound. On the other hand, normal construction tolerances may render the actually built joint somewhat narrower or wider than designed.

## *4.4 HORIZONTAL JOINTS FOR VERTICAL MOVEMENTS*

Although it is easy to construct vertically continuous masonry veneers directly on the foundation wall, this is generally only feasible in low-rise buildings. For high-rise structures, differential movements between veneer and structure become prohibitively large and hence lead to distress, unless horizontal joints are provided which divide the veneer into many low-rise segments, with each segment displaying only small differential movements.[3,4,5,6] As illustrated in Figure 4.1, the concrete frame of a 10-storey building may typically shorten by 15 mm due to elastic deformation, creep, and shrinkage. On the other hand, the clay brick masonry veneer may typically expand by about 15 mm due to moisture and thermal expansion. The resulting differential movement of 30 mm would severely strain:

- veneer ties and window frames in the upper floors of the building; and
- roofing membrane, flashing, and parapet details.

To prevent such distress, the veneer typically is supported at each floor level and a horizontal movement joint is provided as shown in Figure 4.2 for a steel shelf angle support system. Assuming a veneer storey height of 3 m, the vertical differential movement between veneer and frame is about 3 mm, an amount which can be readily accommodated in a reasonably sized movement joint. Using a sealant with a cyclic deformability of ±25 percent and keeping in mind construction tolerances and slab deflections, a 10- to 15-mm movement joint is typically adequate. Note that in Figure 4.2 the movement joint requirement refers to the clear vertical gap between the underside of the shelf angle and the top surface of the veneer. Depending on the thickness of the leg of the shelf angle, the joint width visible on the wall face would be greater and typically of the order of 20 to 25 mm.

A movement joint is also required between non-axial loadbearing backups and the floor slab or spandrel beam above to accommodate deflection of the slab or beam, frame shortening, and thermal expansion of backup. This movement joint will prevent any transfer of vertical load to the backup. SS backups designed to resist only lateral loads are particularly vulnerable to distress, if such load transfer occurs. The width of this movement joint is largely dictated by the elastic and creep deflections of the slab or beam. Depending upon the span, type of construction, and construction tolerances, these slab/beam deflections vary widely and should therefore be computed in each individual case to determine the required width of movement joint.

An additional allowance of 2 mm for the thermal expansion of backup and frame shortening is deemed sufficient for typical storey heights. Specialized anchorage details for a CM backup are dealt with in Chapter 6 and for an SS backup in Chapter 7.

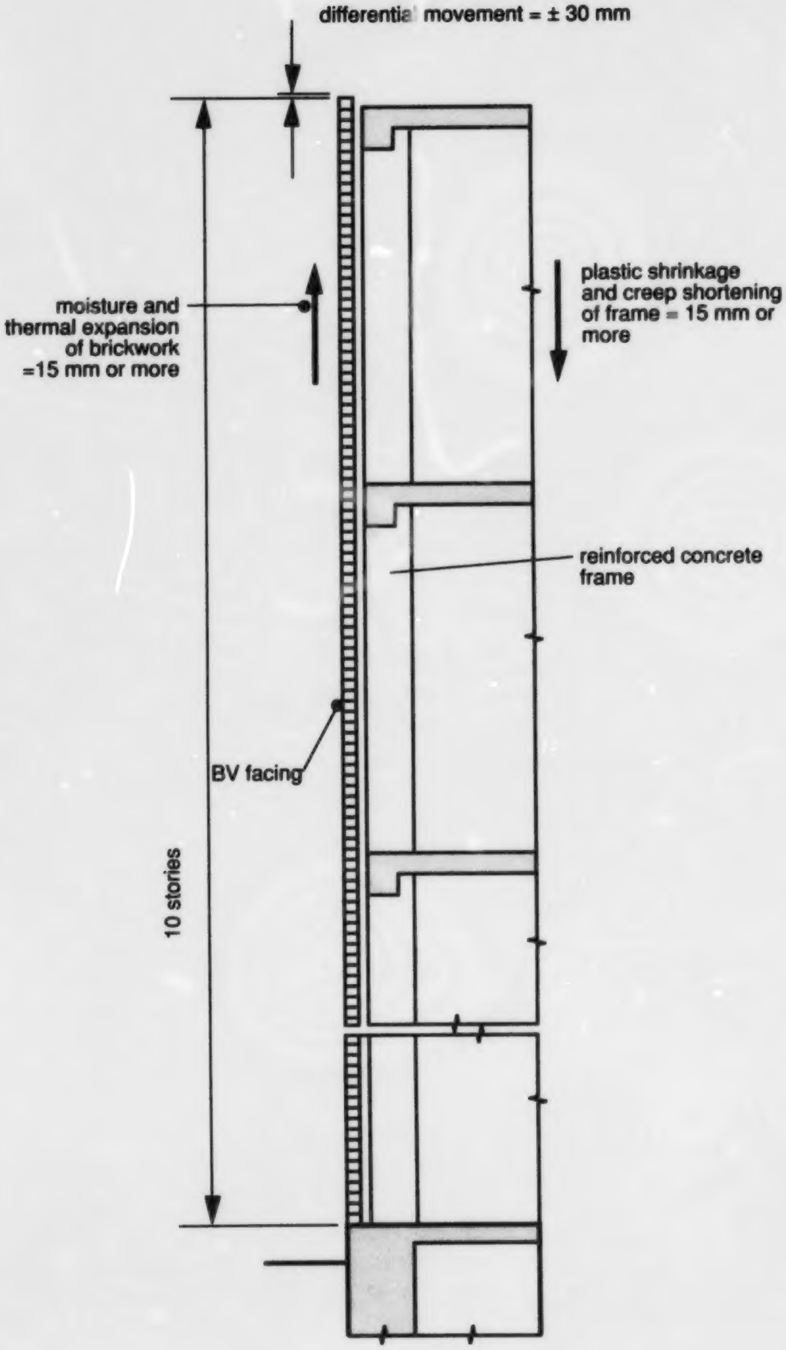
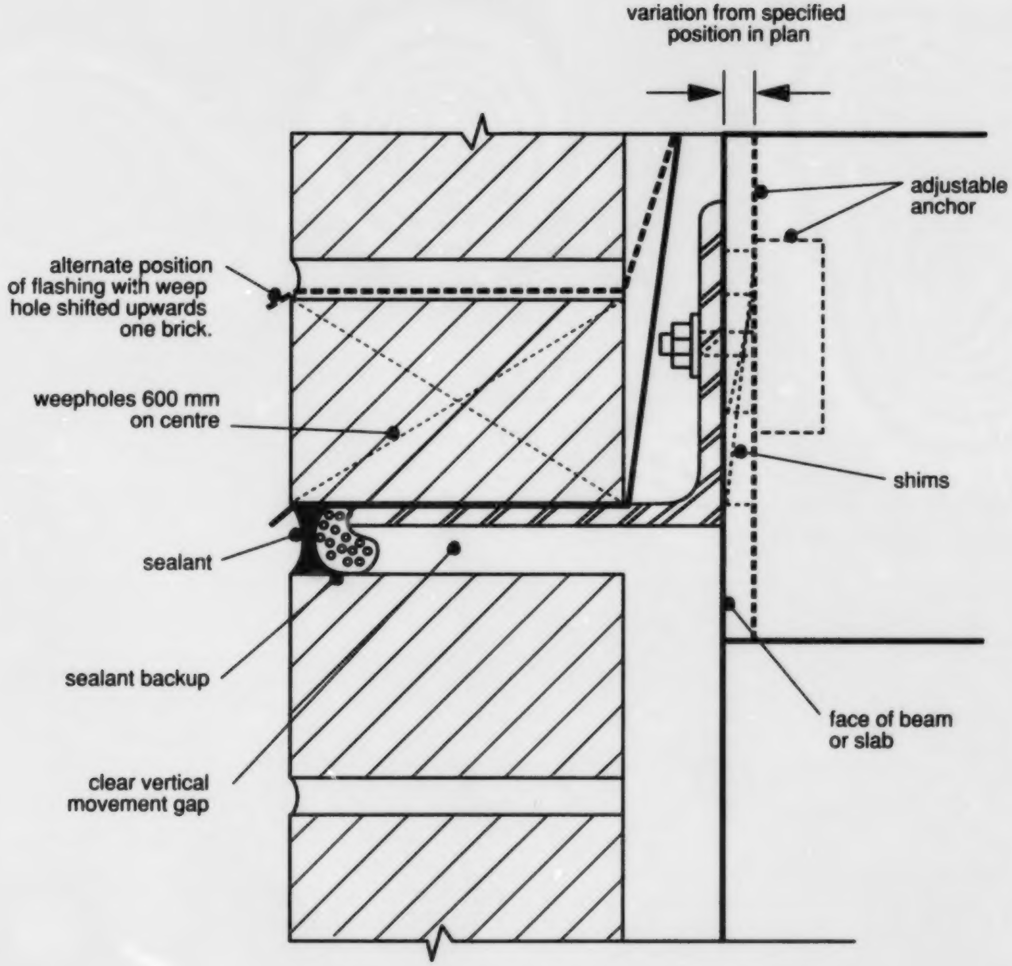

differential movement = ± 30 mm
moisture and thermal expansion of brickwork =15 mm or more
plastic shrinkage and creep shortening of frame = 15 mm or more
reinforced concrete frame
BV facing
10 stories

Figure 4.1 Difference in height of clay brick veneer and frame if relative movements unrestrained


variation from specified position in plan
adjustable anchor
alternate position of flashing with weep hole shifted upwards one brick.
weepholes 600 mm on centre
shims
sealant
sealant backup
clear vertical movement gap
face of beam or slab

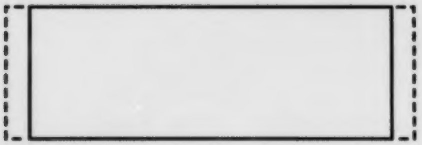
Note: While some designers specify "soft" filler strips in the movement gap, such practice is not recommended for two reasons: some filler strips can transfer significant compressive loads from structure to veneer and an open gap can be more readily inspected.

Figure 4.2 Detail of horizontal movement joint at shelf angle

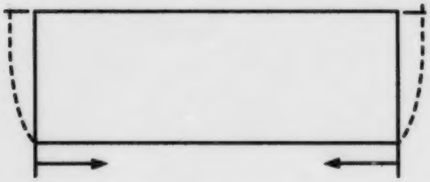
## 4.5 VERTICAL JOINTS FOR HORIZONTAL MOVEMENTS

Movement of masonry veneers also occurs in the horizontal direction. Assuming such movement to be unrestrained, a situation illustrated in Figure 4.3(a), a 15-m long clay brick wall laid up at 20° C could undergo a free expansion of 7 mm. This amount of expansion is based on a moisture expansion of 0.02 percent and a surface temperature increase of 45°C in a hot summer sun. Note that since a wall expands from its centre as indicated in Figure 4.3(a), it will move about 3.5 mm both ways.

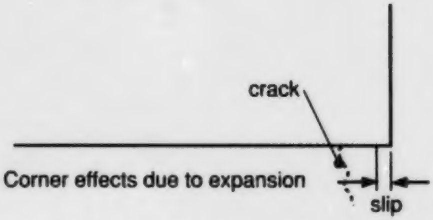
If, instead of being free, the brick wall were on a concrete foundation, the concrete would tend to increase thermally in length by about the same amount for the same assumed temperature change. However, the concrete in a new building will be shrinking and, since it is usually buried in the soil, will therefore be cooler. If so, the foundation will not follow the brick movement completely and, because of friction, will restrain the expansion of the brickwork along the bottom edge. The brick wall will then take on the shape shown in Figure 4.3(b). Generally there will be some slip towards the end of the wall and the brickwork will overhang the foundation a small amount. In slipping, it usually tears away a small piece of concrete as illustrated in Figure 4.3(c). In even longer walls with openings, the strains could cause the type of cracking shown in Figure 4.3(d).



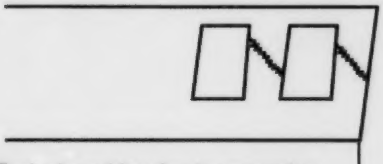
a) Free expansion



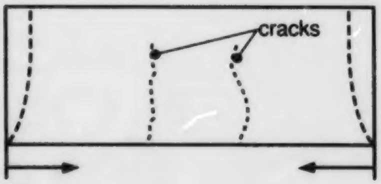
b) Expansion restrained at base



c) Corner effects due to expansion



d) Typical cracking due to expansion



e) Contraction - restraint at base

Figure 4.3 Effects of expansion and contraction on long masonry walls

If the temperature of the brickwork subsequently falls to -25°C or lower in the winter, the overall reduction in temperature will be about 90°C. This large drop from extreme summer conditions will shorten the brickwork by 4 mm at each end, and the wall will tend to take the shape shown in Figure 4.3(e), unless the base of the wall is able to slip along the foundation. Generally, however, there will be some roughness between the concrete and the brickwork, and the restraint of movement can cause large tensile forces. Brickwork is weak in tension and one or more cracks may occur in the wall.

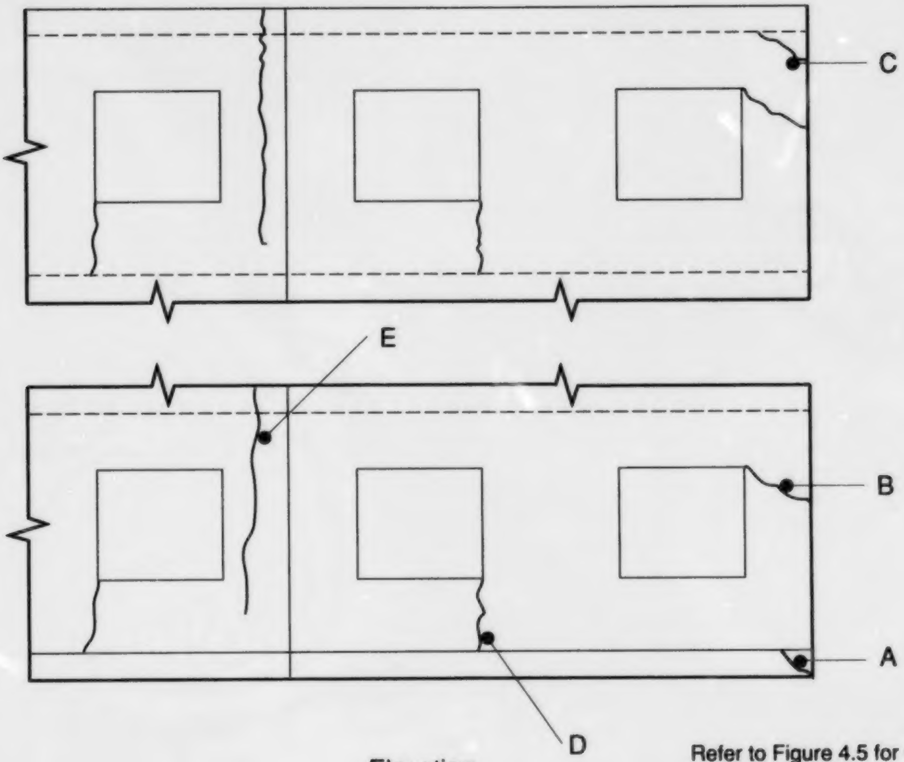
Whether such cracks appear depends on the materials used, the climate, the direction the building faces, the length of the wall, and even the colour of the brick. If the mortar is not too rigid, say a 1:1:6 cement-lime-sand mix or an equivalent masonry cement mortar, the tension may be partially relieved by many fine unobjectionable cracks in the mortar joints. This cannot be entirely relied upon, however, and in long walls it is advisable to provide expansion/contraction joints at frequent intervals. Note that a similar analysis and conclusion applies to concrete masonry, taking into account the fact that concrete has higher thermal movements and shrinks because of changes in moisture content.

In the case of high-rise structures, the base restraint at each support level effectively means that the veneer is made up of a series of low-rise walls and therefore can be treated in a fashion similar to that of low-rise walls.

From the previous discussion it is clear that unrestrained movements rarely if ever occur in practice and that restraint can lead to a buildup of stresses which can crack the masonry. Commonly occurring cracking distress situations in long walls are summarized in Figure 4.4. Figure 4.5 illustrates associated cracking mechanisms. The cracks occur primarily because of the restraint of movement over relatively long horizontal segments of masonry veneer. As is evident from Figure 4.5, corners and window openings introduce some weaknesses in the wall where cracks can occur relatively easily.

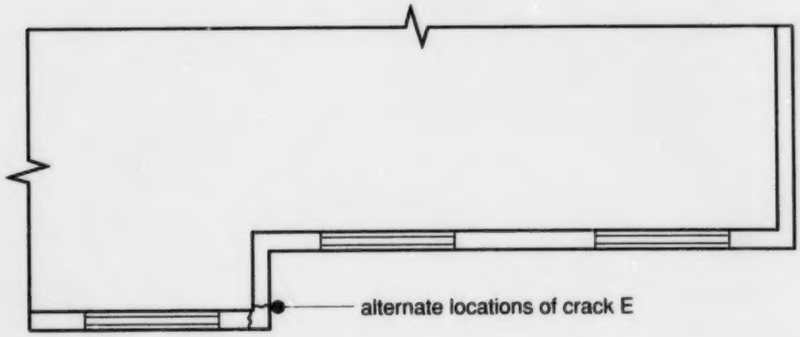
Since movement joints in the veneer require maintenance, an excessive number of joints should not be used. The choice between the minimum number of movement joints and the avoidance of cracking requires computation, tempered by judgment and experience with the materials, the form of the building, and the climate. There are few well-established, simple rules, but evidence based on observation, opinion, and research indicates that the movement joint spacing in the outer clay brick wythe of a cavity wall or veneer should not exceed about 12 m. Concrete block facings require closer spacings of about 8 m.

Residential or office buildings seldom have any wall unpunctured by a window over a length of more than 12 m. Parapets, however, can be quite long. Also, they are subjected to a higher range of temperature and moisture conditions than the wall below due to their greater exposure to weather. Spacing of vertical movement joints in parapets should not exceed 6 m under typical circumstances and should align with other vertical joints in the veneer below.



Elevation

Refer to Figure 4.5 for details on cracks A to E.


alternate locations of crack E

Plan

Figure 4.4 Possible types of cracks in brick veneer due to horizontal movements

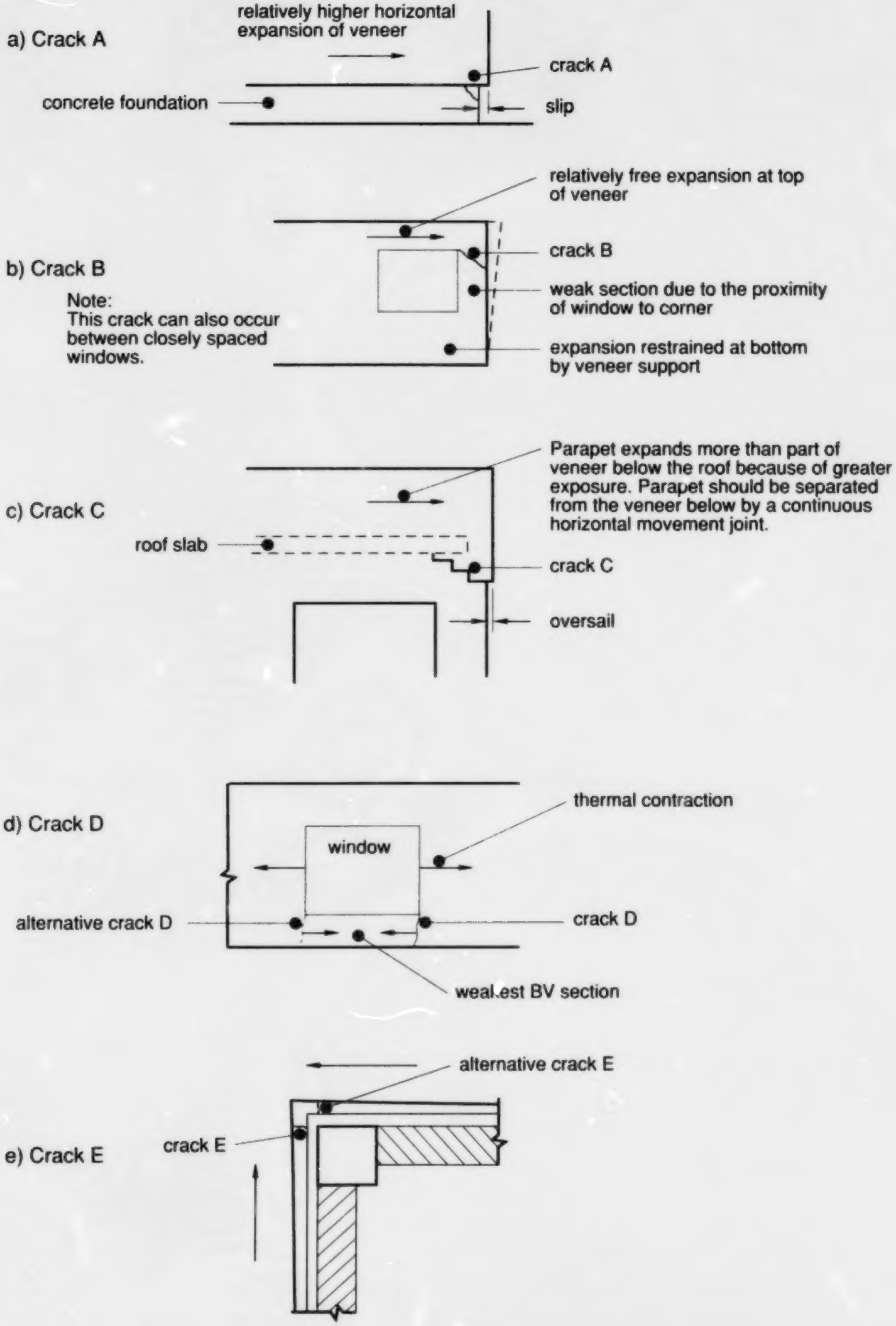
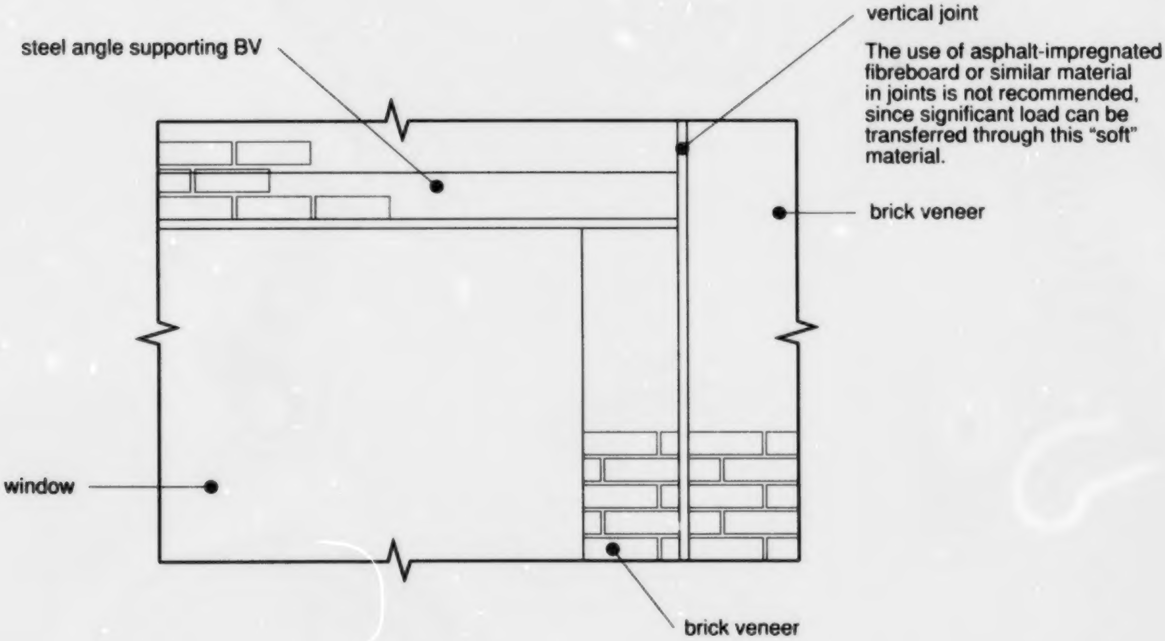

a) Crack A
relatively higher horizontal expansion of veneer
crack A
concrete foundation
slip
relatively free expansion at top of veneer
crack B
b) Crack B
Note:
This crack can also occur between closely spaced windows.
weak section due to the proximity of window to corner
expansion restrained at bottom by veneer support
Parapet expands more than part of veneer below the roof because of greater exposure. Parapet should be separated from the veneer below by a continuous horizontal movement joint.
c) Crack C
roof slab
crack C
oversail
thermal contraction
d) Crack D
window
alternative crack D
crack D
weakest BV section
alternative crack E
crack E
e) Crack E

Figure 4.5 Mechanisms of various types of cracking in BV due to horizontal movement

To avoid crack types A and D (see Figure 4.5), movement joints should be provided, preferably at windows, whenever the unbroken part of the veneer below a window exceeds 10 m in length. It is advisable to continue this joint above the window head. Because of the presence of a steel angle or other veneer support above the window, care must be taken to detail the vertical joint clear of the support's bearing as illustrated in Figure 4.6.

Alternatively, the joint can be placed midway between rows of windows as shown in Figure 4.7. Windows should be located as far away as possible from corners to avoid crack type B. If windows are located within a meter of the corner, a movement joint should be provided in the veneer above the window head within 5 m from the corner. To avoid cracking of type E, returns shorter than a metre should be avoided or a movement joint should be provided at the corner preferably in the longer wall. If the runs of veneer expanding into the corner are both long, there should be a joint close to or at the corner in both walls. Wherever a movement joint is present in the main structure, a



The use of asphalt-impregnated fibreboard or similar material in joints is not recommended, since significant load can be transferred through this "soft" material.

Figure 4.6 Vertical joint detail in brick veneer near opening

corresponding movement joint should be provided in the veneer.

Joints in brick veneer are often made opposite to columns or cross-walls, so that the two sides of the joint can be anchored to the support with flexible ties as indicated in Figure 4.8.

Further discussion of vertical joints for horizontal movements may be found in the references at the end of this Part.[7,8,9,10] The Technical Note on Brick Construction, No. 18, issued by the Brick Institute of America, recommends that they be placed in long walls and at offsets, junctions, corners, and parapets as illustrated in Figure 4.9.

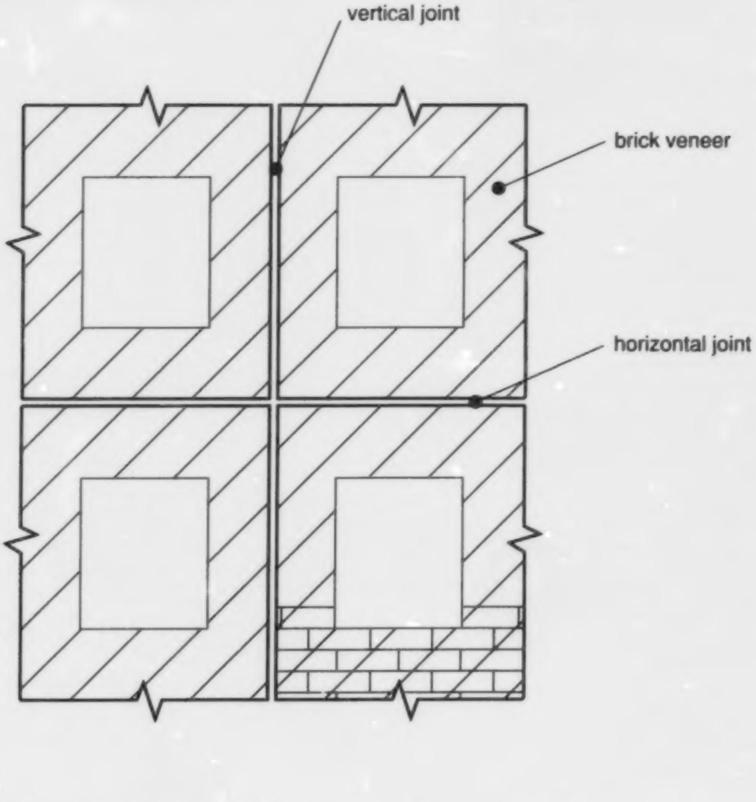


Figure 4.7 Vertical joint midway between rows of openings

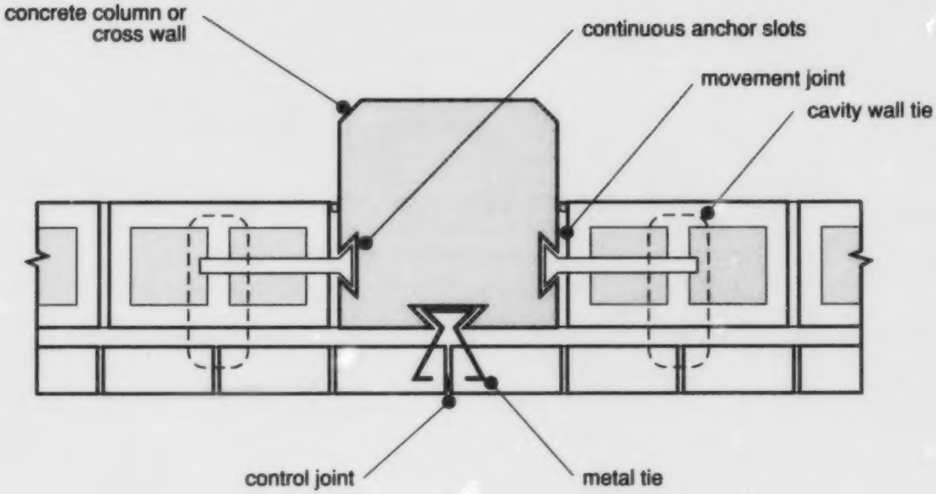

concrete column or cross wall
continuous anchor slots
movement joint
cavity wall tie
control joint
metal tie

Figure 4.8 Movement joint at column

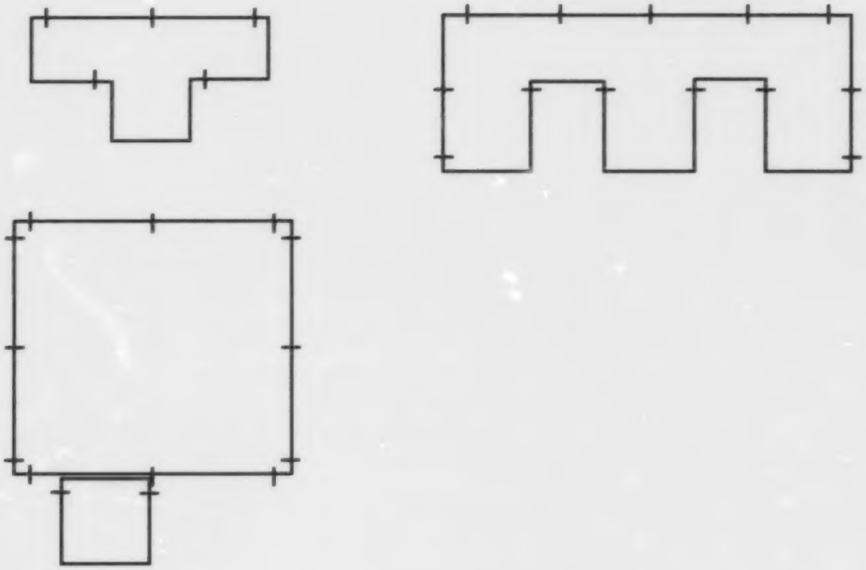


Figure 4.9 Typical locations of movement control joints

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# CHAPTER 5

# STRUCTURAL COMPONENTS COMMON TO VENEER WALL SYSTEMS

## 5.1 INTRODUCTION

This section contains a discussion of the structural design of the elements of BV walls common to CM and SS backup systems. Advice for the structural design of the BV/CM wall system will be covered in Chapter 6 and for the BV/SS wall system in Chapter 7. Some discussion of identifiable areas of vulnerability will be included in each of these chapters.

## 5.2 BACKUP WALL

The interior wall has been called the backup wall because it normally provides the structural backing for the brick veneer. As such it has been traditionally designed to resist all of the lateral load- and to transfer the lateral load to the main structure of the building. For structural safety, the veneer-backup wall concept ensures that the loads applied normal to the wall can be adequately resisted.

The backup wall can be designed independently from the brick veneer. For loading, a uniform distribution of the total load is a reasonable assumption. (Note: Where the brick veneer is more than 10% higher than the backup wall, the design load on the backup wall should account for the potentially greater tributary area.) The capacity requirements for the backup wall will be affected by the direction of its span (vertically, horizontally, or both), and by the extent of openings and methods of transferring forces from these areas to the supporting structure.

For large windows or other openings, significant increases in the wall's load-carrying capacity may be required on either side of the opening. Also, the backup wall must be joined to the structure in a manner consistent with the intended function. At the base, the backup wall will normally be anchored to the floor, but at the top, the fact that a movement joint is required means that rigid connection is not acceptable and special details are required.

For CM walls which are built into moment resistant frames, the inter-storey drift can result in in-plane forces being exerted on the wall. Therefore, unless the backup is designed as structural infill to be part of the load-resisting structure, appropriate gaps (in the order of storey height/500) are required along the sides and connections to the columns must permit this movement. Where the main structure is a shear wall structure, the inter-storey drift is usually sufficiently small so that SS backup walls can be built in tight to the side supports. The more rigid CM backup may still require some clearance.

Even though the brick veneer may not be relied upon to share in resisting lateral load, the fact that it is connected to the backup wall means that it does share in resisting the load. Since the strength and stiffness of brick veneer cannot simply be legislated out of existence, the veneer and backup wall will actually function as a cavity wall up to the point where the stiffness of the veneer changes due to cracking, after which load-sharing is less significant. As will be discussed regarding rain leakage, in order to limit crack width, the backup wall may have to be designed in conjunction with the brick veneer to satisfy serviceability conditions for the brick veneer as well as for itself.

Since the veneer and backup wall may not be of equal height or length, nor have the same support conditions, nor be tied together by rigid ties, calculations which distribute the load to each wythe in proportion to their structural section stiffness (EI) will at best be very approximate.[1] Notwithstanding the above, at the extremes, where one wall is much stiffer than the other, this type of analysis provides a reasonable approximation of the bending stresses in the stiffer wall element. Where the backup wall is much stiffer than the veneer, as in the BV/CM system, it is unlikely that flexural cracking or unacceptable deflections will occur in the veneer.

Alternatively, where the veneer is much stiffer than the backup, as in the BV / SS system, the deflection of the veneer before cracking and the cracking loads can be reasonably assessed by considering that the veneer carries either all the load or nearly all the load in proportion to the relative stiffnesses of veneer and backup.

Where the veneer and backup wall have similar flexural stiffnesses, the factors mentioned above have a much greater effect on the distribution of load between the two and an assessment of the bending stresses requires a much more rigorous structural analysis to incorporate these influences. Similarly, such a rigorous analysis is required for an accurate assessment of deflections, tie forces, and reactions. This analytical approach is also needed to determine stresses in relatively flexible backup.

In summary, the backup wall will normally be designed to carry the full lateral load and, in the case of a stiff backup, to be sufficiently stiff to prevent cracking of the veneer. Alternatively, where a relatively flexible backup wall is used, it should be designed to limit the overall deflection of the wall system to within acceptable values; at the same time, it is recommended that the brick veneer have sufficient strength to carry most of the load up to some level at which cracking is considered acceptable. The discussion of criteria for the cracking load on veneer is included in Chapter 10 where serviceability is closely related to building science functions of the wall. Deflection limits are also discussed in Chapter 7.

## *5.3 BRICK VENEER*

Brick veneer provides not only a pleasing aesthetic appearance, but also a durable barrier to wind and rain. In the latter capacity it sheds some of the incidental rain directly and prevents any water that does penetrate it from reaching the inner backup wall by virtue of its draining cavity. To a significant extent the amount of water penetrating a veneer is limited by its degree of pressure equalization through application of the open rain screen principle. It is expected to perform these functions better if it remains uncracked. Therefore design criteria must set out the conditions under which cracking is acceptable. The extra precautions or introduction of special design details which may be necessary to accommodate the potentially greater water penetration through cracked veneer must also be clearly shown.

For cases when the only feasible design is to allow cracking at some stage of loading below the full design load, it is still worthwhile to assess the level of load at which cracking is expected. In fact, specification of some minimum load to be carried before cracking could serve as a lower-bound serviceability limit. Since in many cases walls are never subjected to the full design load and since secondary strengthening effects are often present, many such walls may not crack in service. Although it is necessary for the design to accommodate the potentially increased water penetration due to cracking, the occurrence of rain-penetration-related problems will be reduced because of the smaller proportion of walls which crack. This concept is discussed in more depth in Chapters 9 and 10.

It should be noted that the support conditions have marked effects on the cracking capacity of brick veneer where support around all sides of a panel will significantly increase the cracking load. Since ties and anchors transfer load between the brick veneer and the backup wall or main structure, the stiffness and location of these also affect the cracking capacity. Conservatively, for the cracking load, the veneer can be designed independently by using simple support conditions and applying the portion of the load calculated on the basis of relative EI values.

That is

$$P_{bv} = P_{total} \frac{EI_{bv}}{EI_{bv} + EI_{backup}}$$

(Equation 5.1)
where

$P_{total}$ = total uniformly distributed lateral pressure

$P_{bv}$ = uniformly distributed lateral pressure applied to the brick veneer.

If the backup wall or main structure does not provide unyielding support, evaluation of the load-carrying capacity of the veneer by itself is a conservative alternative to a rigorous analysis.

Computer programs such as a plane frame analysis can be used for structural analysis of BV wall systems. The results of these analyses provide reasonably accurate information which allows detailed examination of the effects of design decisions.

Where cracking of the brick veneer occurs, much of the load on the veneer is transferred to the backup. Especially for high walls, the potential for additional cracking must be considered where instability of the veneer could result from a crack spacing less than twice the tie spacing. Figure 5.1 illustrates this feature. Since the location of cracks in the veneer also affects the tie forces, analysis of potential crack patterns may be required for unusual wall geometries.

Brick veneer must span over openings. Typically a lintel angle is used over small openings where the load carried by the lintel is defined by a 45° triangle as shown in Figure 5.2. As was discussed in Chapter 4, it is important to note that this lintel cannot be attached directly to the structure. Where large openings exist, it is usually best to introduce vertical joints through the veneer in line with the edges of the windows. In these cases, as shown in Figure 5.3, the veneer panels above the openings can be supported on shelf angles attached to the structure. These shelf angles must not extend across the vertical joints. In other ways, this is a good idea since it removes the possibility of cracks initiating at the corners of openings.

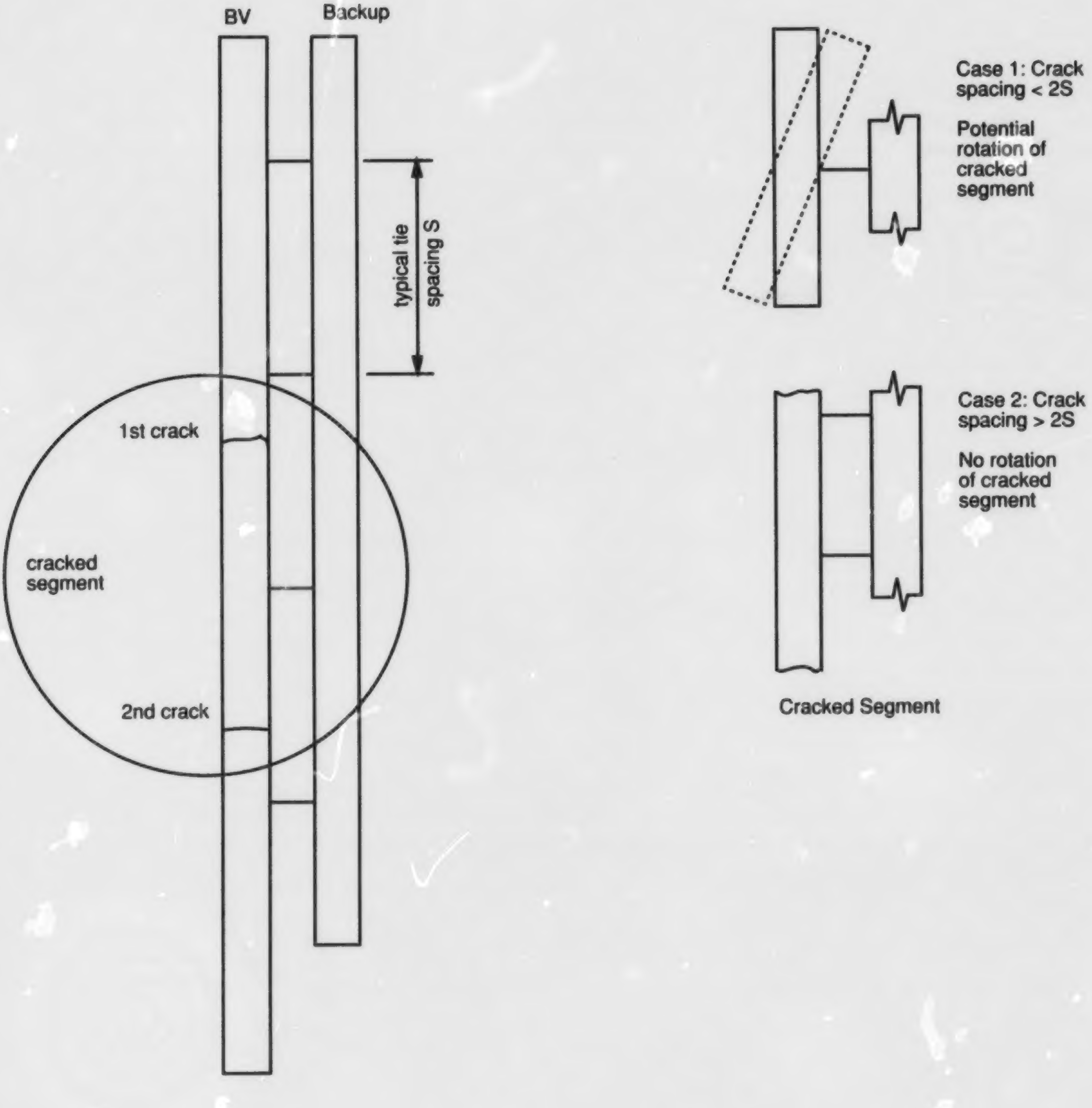

BV
Backup
typical tie spacing S
1st crack
cracked segment
2nd crack
Case 1: Crack spacing < 2S
Potential rotation of cracked segment
Case 2: Crack spacing > 2S
No rotation of cracked segment
Cracked Segment

Figure 5.1 Illustration of potential instability of cracked veneer for large tie spacing

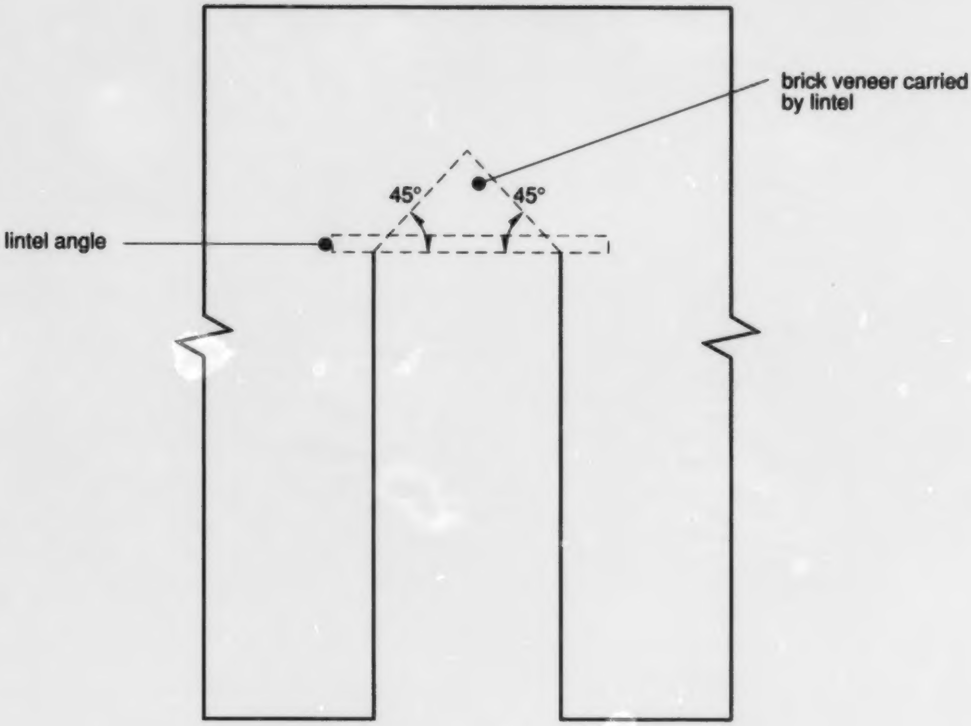

brick veneer carried by lintel
45°
45°
lintel angle

Figure 5.2 Loading on lintel angle over opening

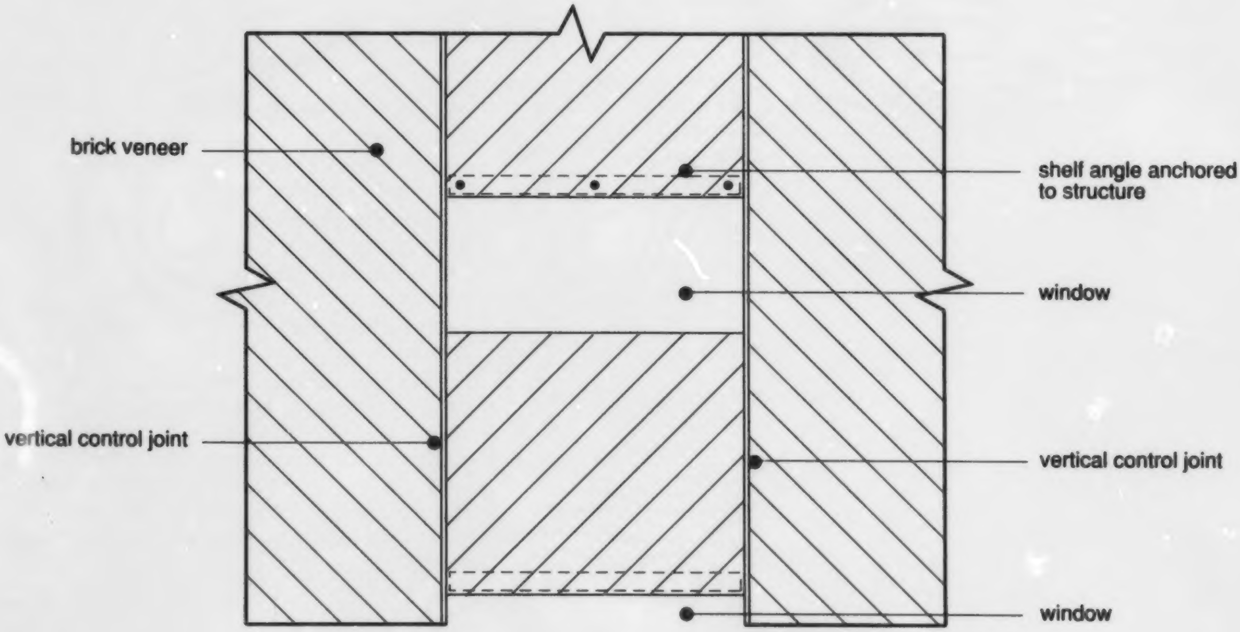

brick veneer
shelf angle anchored to structure
window
vertical control joint
vertical control joint
window

Figure 5.3 Separate shelf angles for support of veneer over openings

## *5.4 VERTICAL SUPPORT FOR BRICK VENEER*

There are basically two ways in which veneer may be supported:

1. The most common method is for the brick veneer to be supported on a shelf angle as shown in Figure 5.4. The veneer then spans a full storey height, but while the base is supported both laterally and vertically by the shelf angle, the top is free of the next shelf angle and therefore its effective line of support is the uppermost line of ties. Details of the design of the shelf angle system and points to consider in detailing are included in the next section.
2. A method of construction, which has been popular because it avoids the need for shelf angles and permits construction without external scaffolding or swing stages, is to support both the veneer and backup wall on the floor slabs of the building. This construction method can lead to problems with the adjustments that the mason must make to compensate for differences in storey height or in alignment of the floor edges.

The advantages of reduced construction effort and materials, and hence fewer details that can go wrong tend to be offset by some building science issues (such as the potential for water penetration, heat loss, and cold interior finishes) and by the architectural limitations of exposed floor slabs.

## *5.5 STRUCTURAL REQUIREMENTS FOR SHELF ANGLES*

The shelf angle itself must be designed to carry the weight of the veneer on the extended leg of the angle where bending must be calculated for the maximum outward position of the veneer. The anchors of the shelf angle to the structure provide the shear resistance for the weight of veneer and are the tension component of the couple which provides the moment resistance at this support. Typically bolts or welded anchors should not be spread farther apart than 1.2 m and should be sized to carry the shear and bending forces.

Shelf angles must provide a continuous unbroken support for veneer. At corners this may require mitering of the intersecting pieces to ensure this continuity.

As illustrated in Figure 5.5, the applied moment is the weight of the veneer multiplied by the distance from the face of the support. The resisting moment is the tensile force times the distance to the compression component of the couple. Therefore, it is very important that the correct type of shims be used to provide horizontal adjustment.

Use of washers will result in small distances between the tensile and compressive forces and produce overstressing of the concrete under compression. Rotation of the angle may result.

A major decision in the design of the shelf angle is to what extent its position can and should be made adjustable. If the shelf angle is fixed in position at the time of concrete placement for the structural frame, its location both vertically and horizontally is tied to the construction tolerances of the frame.

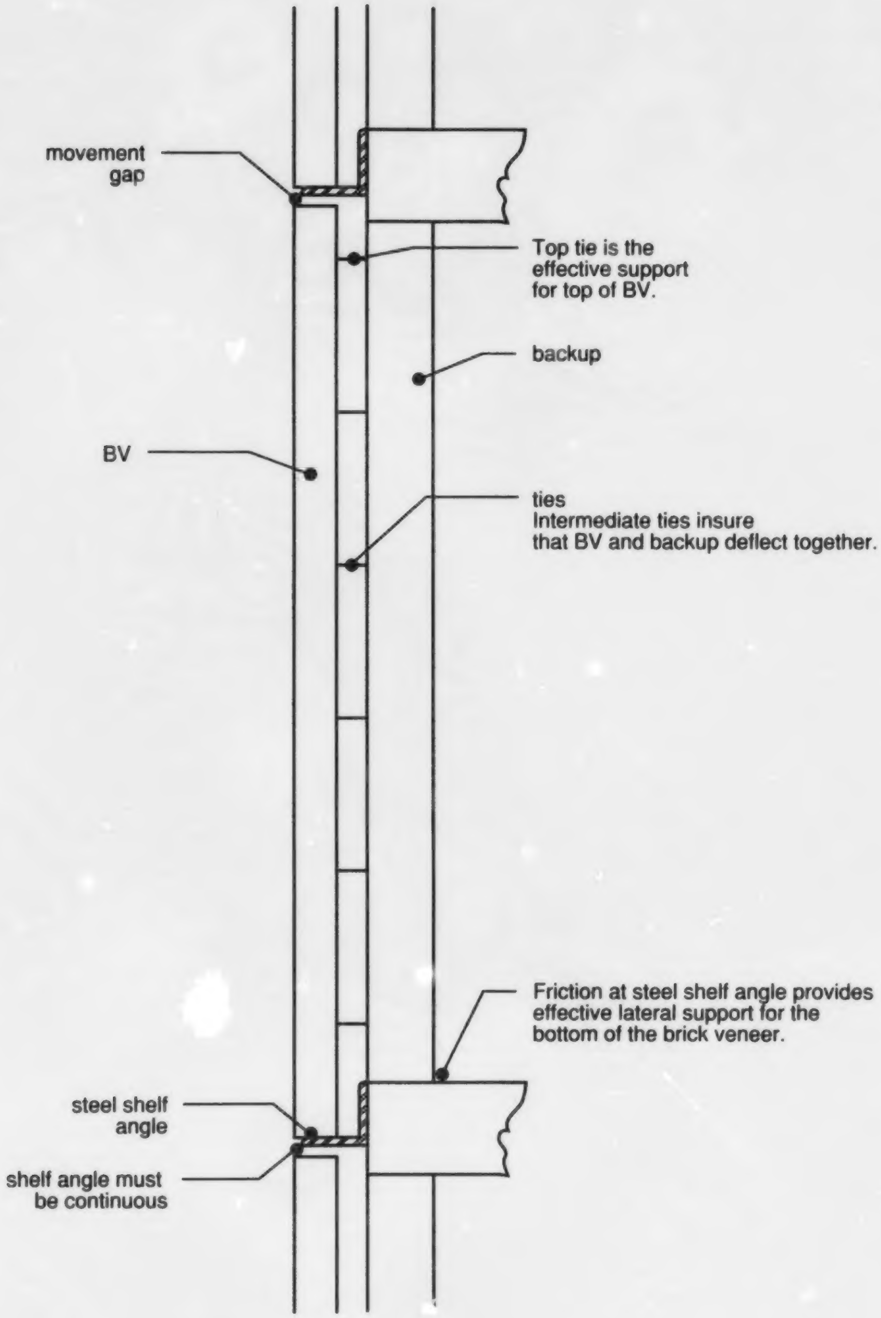

movement gap
Top tie is the effective support for top of BV.
backup
BV
ties
Intermediate ties insure that BV and backup deflect together.
Friction at steel shelf angle provides effective lateral support for the bottom of the brick veneer.
steel shelf angle
shelf angle must be continuous

Figure 5.4 Shelf angle support system for BV

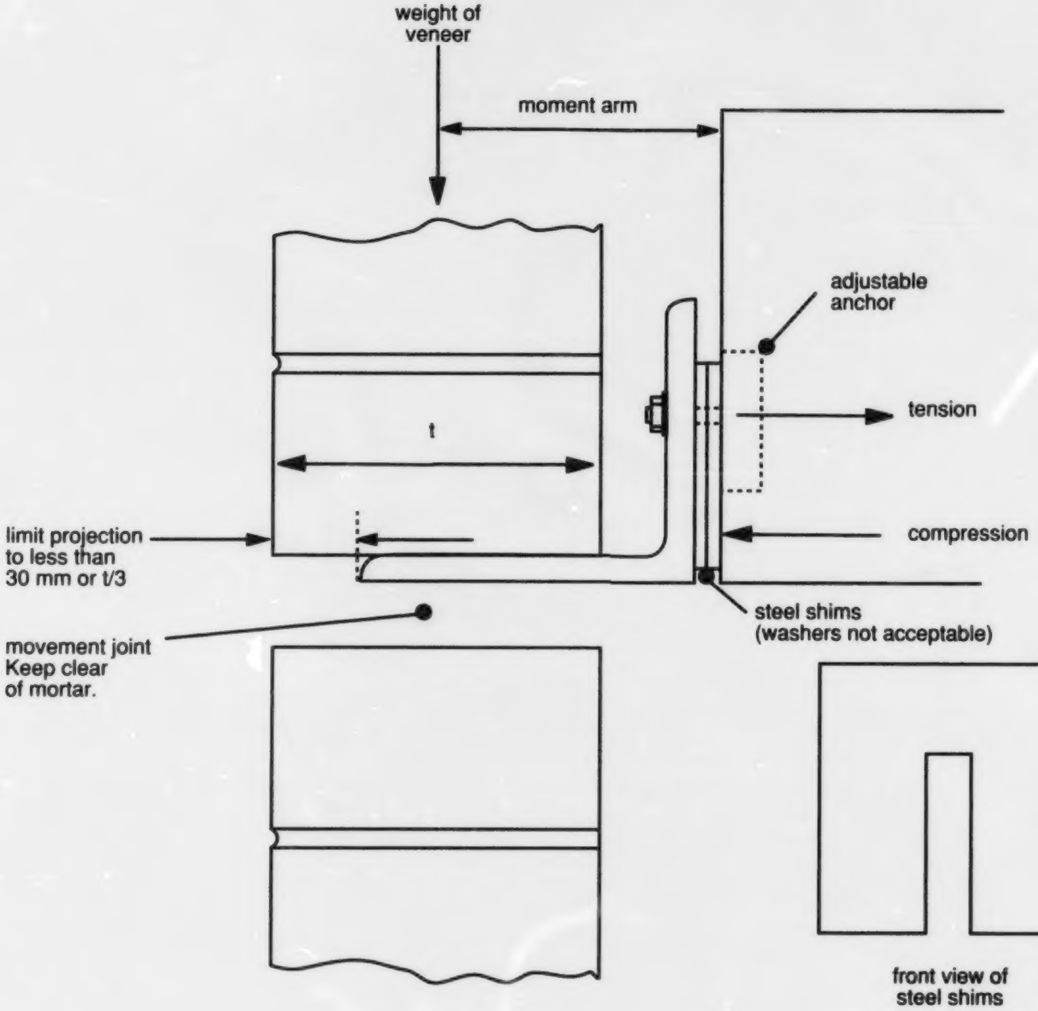

weight of veneer
moment arm
adjustable anchor
t
tension
limit projection to less than 30 mm or t/3
compression
steel shims (washers not acceptable)
movement joint Keep clear of mortar.
front view of steel shims

Figure 5.5 Design of shelf angles

Such a method of shelf angle attachment presents some advantages and disadvantages:

*ADVANTAGES:*

- Attachment to the frame, usually by means of a cast-in strap anchor, is secure.
- The construction is simple and straightforward and hence can proceed with a minimum of potential slip-ups and a minimum of site supervision.

*DISADVANTAGES:*

- Because of construction tolerances, variation in the vertical position of the shelf angle can result in either too large or too small a gap for the movement joint underneath the angle. Although the mason can accommodate these variations to some extent, joints of varying widths and undulating base lines may present aesthetic problems.
- Variations in the horizontal position of the shelf angle can only be accommodated by varying the bearing area of the brick on the shelf angle. Since the brick may not project beyond the toe of a shelf angle by more than 30 mm or one-third of the brick width, such adjustments are limited and may require special care by the mason.
- Placement of the top course of bricks below the shelf angle may be difficult.

Alternatively, an adjustable shelf angle attachment is possible by means of cast-in anchors or drilled-in anchors. This attachment method has the following advantages and disadvantages:

*ADVANTAGES:*

- Vertical adjustment is possible by means of slots in the shelf angles.
- Horizontal adjustment is achieved by means of shims.
- Good aesthetics are provided due to even joint widths.

*DISADVANTAGES:*

- Cast-in anchor bolt locations may not match shelf angle slots.
- Drilling-in of new anchors or enlarging slots in the shelf angle are common means of correcting mismatched slots. Note that the often-used technique of burning out a larger hole destroys the corrosion protection locally and therefore requires touch-up painting which may not be as effective as the factory-applied protection. The enlarged slot also often does not leave sufficient bearing surface for the nut and washer.
- Greater construction care and inspection effort are required to assure proper alignment of the shelf angle, proper use of shim plates, and proper torquing of the friction connection created by tightening the nuts on the anchor bolts. Note that for long anchor bolts embedded in concrete, creep and shrinkage in the concrete may result in some reduction of the tension in the anchor bolt. Also for drilled-in anchors, care must be taken to clean out holes to ensure the development and maintenance of specified tensile forces.

## *5.6 TIES*

The adoption of standard CAN3-A370 (*Connectors for Masonry*)[2] by the National Building Code in 1985 has had the beneficial effect of focusing attention on the need to evaluate both the structural and long-term performance of ties. The standard provides guidance for methods of evaluating ties and the safety factor which should be associated with various potential modes of failure. However, the actual strength and stiffness requirements are not directly specified, and tables for horizontal and vertical spacings imply a uniform tie force or tributary area concept for ties and that is not correct.

Both full-scale tests and detailed structural analysis have shown that the top tie fastening veneer to the backup wall is by far the most highly loaded, and for flexible backup walls, this load may approach half of the load on the wall. Therefore, ties must be designed either for these higher forces or for closer horizontal spacings near the top of the brick veneer.

Before recent attention to the structural performance of ties, the major concern, other than cost, was to suit the ties to the construction process. This has led to a wide variety of what are known as adjustable ties in that non-alignment of mortar bed joints can be accommodated. From a point of view of structural stiffness, some of the ties available are inadequate. Of concern, other than the flexibility, is the free play which some forms of adjustment (i.e., oversized holes) incorporate. As shown in Figure 5.6, a tie with vertical adjustment provided by the leg of the tie can be quite flexible yet have limited strength. This factor must be taken into account in the selection of ties.

Also, as shown in Figure 5.7, ties should be capable of carrying loads even in cases of extreme deformation. In addition, the effect of workmanship, such as bending in the field, and general alignment all could lead to considerable weakening and reduced stiffness. There are recent standards and research on these topics.[3, 4, 5, 6, 7, 8, 9]

In this respect, the indentation or drip which had been incorporated into many types of ties to prevent water from flowing across the cavity has been eliminated by the standard in order to provide stiffer and stronger ties.

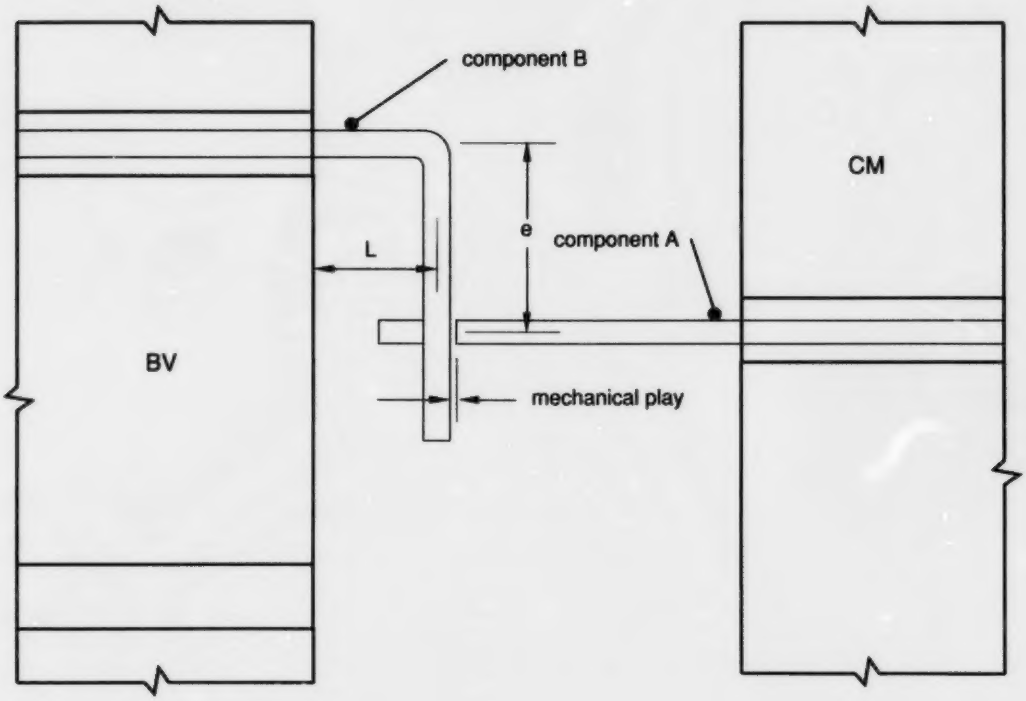
Corrugated strip ties have been in common use in Canada and a minimum thickness as low as 28 gauge has been incorrectly used in some highrise construction. Although 22-gauge corrugated ties are allowed by the NBC for cavity width up to 25 mm, bends in the ties can have very large effects on their tensile stiffness and compressive buckling strength.[10] Therefore, unless close control of bending can be obtained on site, use of corrugated strip ties is not recommended for high-rise construction.

Where screws or dissimilar materials have been used, corrosion has been a major concern for the long-term properties of the ties.[11] Therefore, ties which were once only mill-galvanized now are hot-dipped.[12] Some designers require stainless steel or other non-corroding materials especially under aggressive environmental conditions.

Ties connecting the brick veneer to the backup should be chosen to satisfy the conditions discussed in the following section.

### *ADEQUATE STRENGTH AND STIFFNESS*

Ties should be capable of transferring both tensile and compressive forces. Although in the past the tie forces have been considered reasonably evenly distributed, this has been shown to be untrue. Where the veneer does not crack, the top ties must be relied upon to transfer the reaction for the share of the load carried by the veneer. Alternately, after cracking, ties near a mid-height crack will be required to transfer approximately half of the load on the veneer to the backup wall.



Example of influence of adjustability

If the wire of component B is 4.76 mm in diameter (D) with a yield strength (fy) of 400 MPa, using a load factor (LF)= 3.0, the force (F) which can be transferred is dependent on the eccentricity (e). Therefore

$$F= \left[ \frac{Z}{e} \; \frac{(fy)}{3} \right]$$

With elongation of the wire not taken into account, the displacement due to bending of the wire is

$$\triangle = \frac{1}{EI} \left( Fe^{2} L + \frac{Fe^{3}}{3} \right)$$

For minimum adjustment e = 4.76 mm

$$F = 1.7 \; \frac{\pi \, (4.76)^{3}}{32} \; \frac{400}{3} \; \frac{1}{4.76}$$
$$= 505 \text{ N}$$

At F = 505 N and L = 20 mm, $\triangle = 0.05$ mm

For an adjustment e = 30 mm

$$F = 1.7 \; \frac{\pi \, (4.76)^{3}}{32} \; \frac{400}{3} \; \frac{1}{30}$$
$$= 80 \text{ N}$$

At F = 80 N and L= 20 mm, $\triangle = 0.43$ mm

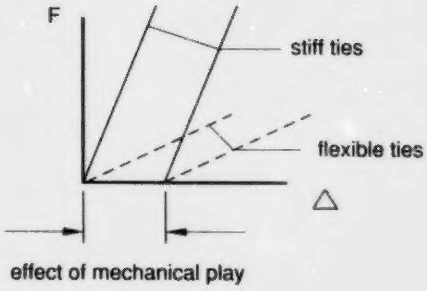
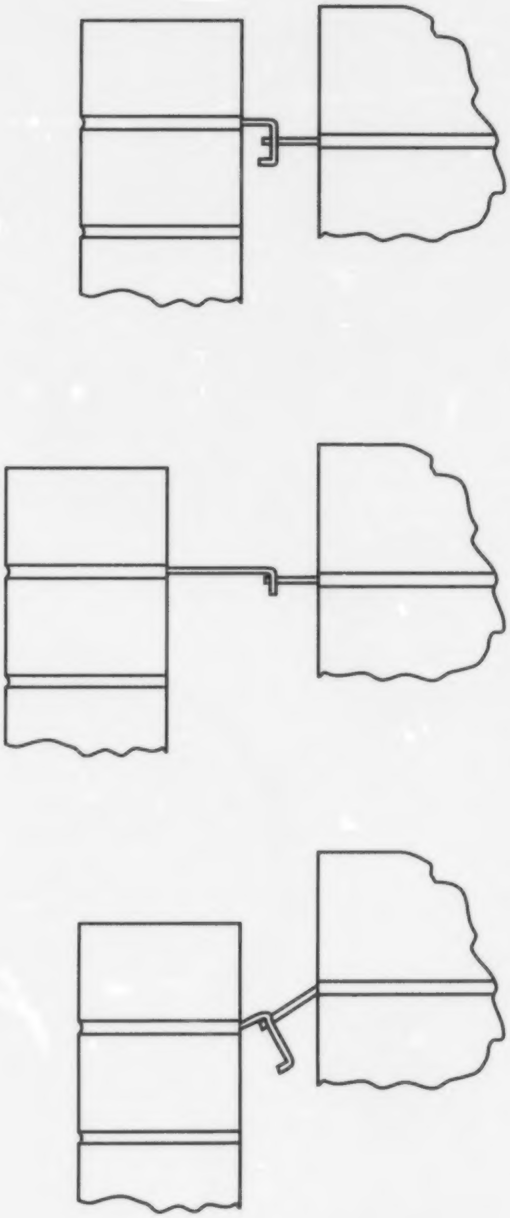


Figure 5.6 Effect of adjustability on tie capacity



a) Original condition

b) Outward movement
of veneer

maintaining load
transfer after
yielding of tie

c) Downward movement
of veneer

maintaining load-carrying capacity
after extreme damage

Figure 5.7 Illustration of requirement for ties to maintain load-carrying capacity after initial failure

The strength and stiffness should include the influence of the embedment in mortar joints or attachment to the backup wall. Flat, corrugated ties should not be used. Where two piece adjustable ties are used, the wire part of the tie should be embedded 50 mm into the veneer. Also, ties should neither have mechanical play in excess of 0.8 mm nor deform over 1.2 mm at 0.5 kN load in either tension or compression. This latter is a minimum specification and higher stiffnesses may be required where large forces are transferred by ties (i.e., top tie reactions). CSA Standard CAN3-A370-M84 should be consulted for applicable load factors. Test data, including strength and deformation information, for the full range of adjustability should be required before any tie is specified for use.

### *ADEQUATE CORROSION PROTECTION*

Since deterioration of ties may lead to an unsafe veneer, the corrosion potential should be carefully evaluated for the building environment. In many cases the small incremental cost to the wall system of specifying non-corroding ties will be sound design practice. (See CAN3-A370 for information on required corrosion protection.)

### *SUITABILITY FOR METHODS OF CONSTRUCTION*

Sequence of construction and requirements for precise layout are major factors in the choice of tie system. Ties which protrude into the veneer space may interfere with brick laying and hence are commonly bent out of the way. This may damage the tie and result in loss of strength and stiffness.

A two-part tie system is frequently used to overcome this problem: one part placed as the backup is built while the other part inserted subsequently as the veneer is built up.

This practice of building the brick veneer after the backup wall has led to the development of many adjustable ties. These should retain adequate stiffness and strength through the full range of adjustability and the total movement in the connector plus the deflection of the structural backing should be controlled to limit cracking of the veneer.

### *SUITABILITY TO DESIGN OF THE WALL COMPONENTS INCLUDING NON-STRUCTURAL COMPONENTS*

Ties must fit in with the overall construction scheme; that is, it must integrate the stage of construction with functions of the components connected to or otherwise interacting with the ties. Therefore, where air barriers or insulation are used on the outside of the backup, the performance of the ties should not be affected by bending them to accommodate insulation and exterior sheathing.

### *SUFFICIENT ROBUSTNESS TO WITHSTAND HANDLING AND USE UNDER JOB SITE CONDITIONS*

Ties which may be easily damaged (bent, welds broken, corrosion protection removed) during handling are not suitable for job site conditions. Similarly, ties which are difficult to align or interconnect may either be damaged during installation or may have substantially weakened properties as a result of poor placement procedures.

## 5.7 ANCHORS

In the context of this Advisory Document, anchors are devices which are used to attach the backup wall or brick veneer to the supporting structure (for instance, using dovetail anchors to concrete columns). Therefore, in the case of the backup walls, they must be capable of transferring the horizontal shear forces. In addition, at least at the top of the wall, the types of anchoring systems must allow unrestrained vertical movement at the movement joints.

Where walls are attached to the supporting structure along the sides, the anchors may or may not be required to permit horizontal movement depending on whether the walls are to be built tight to the structure. Regardless of this, there is a need to accommodate vertical movement, due to frame shortening, along the sides of the walls.

While side anchors can present some difficult construction detailing problems, from a structural point of view, the strength gain for walls supported on all sides or (as is the case for large windows) for walls supported on three sides can be quite appreciable.

CSA Standard CAN3-A370 (*Connectors for Masonry*) covers design and construction for a variety of anchors including so-called standard anchors.

## 5.8 OPENINGS

The backup wall must be designed to carry the load transferred to it by the framing around the opening, and the framing must be securely anchored to the backup wall. In most instances the joint between the frame and the veneer should be a movement joint and the interaction between veneer and backup should be provided only by the extra ties around openings.

The support of veneer above openings is typically achieved by a steel angle or other structural steel section. This member bears on the veneer and must not be connected to the backing or the structure, unless dealt with as shown in Figure 5.3.

It should be noted that openings represent the weakest part in the wall and have the most potential for crack initiation. To control cracking, movement joints must be carefully designed to avoid buildup of stresses.

## 5.9 KEY CONSTRUCTION REQUIREMENTS

From the preceding discussion and additional considerations, the following key requirements for construction stand out:

- Before constructing the BV and the backup walls, the alignment, plumbness, and spacing of floors, columns and other components must be within acceptable limits. Otherwise corrective measures must be completed before commencing construction. Corrective measures must be approved by the engineer or other authority responsible to the owner.
- The brick veneer should be constructed with full head and bed joints, and have joints tooled to achieve good bond and water resistance. Type N or S mortar should be used as specified where control by either the proportion method or by cube tests is required.[13]
- For shelf angles supporting veneer:
    - the vertical alignment of floors or edge beams should be sufficiently close that the overhang of the veneer with respect to the toe of the shelf angle is within accepted tolerances (see Figure 5.5);

- for bolted connections, field adjustments by shimming or torch-cutting must be approved by the engineer. Where shimming is required, proper shims shown in Figure 5.5 must be used;
- where large variations in vertical alignment exist, drilling in of new anchors or replacement of shelf angles may be necessary to provide a smooth and even surface over the height and width of the building while retaining the specified cavity width;
- when field adjustments are made, touch-up painting or other approved procedures must be used to re-establish the corrosion protection;
- in the case of cast-in anchors, lack of adjustability makes it especially important that existing construction be measured up and problems resolved before installing the wall system; and
- the provision of the specified clear movement gap at the top of the veneer and backup is essential. Shelf angles must be firmly anchored to the structure to maintain the gap, and mortar must be kept out of this space.

- For slab supported veneer, the tolerance related to slab edge versus veneer overhang is very tight. Not only must the veneer have adequate bearing but the top of the veneer must fall sufficiently under the slab to be protected from direct exposure to rain water running down the face of the building. Some of the construction requirements are illustrated in Figure 5.8.

  Although a popular detail in some parts of Canada, leakage problems[14] or thermal bridging associated with support of the veneer on the floor slab have led to a reduced use of this detail. Although shown for illustrative purposes, it is not a recommended detail.

- Installation of ties must assure that
  - ties and joint reinforcement are properly embedded in mortar[15] (The practice of placing a tie on top of the bare masonry unit and covering it with mortar is not acceptable. Instead these components should be completely embedded in the mortar joint.);
  - damaged ties must not be used and ties installed must not be bent or otherwise damaged during construction. (Figure 5.9 contains sketches of some concerns regarding tie placement.); and
  - the spacing for ties must be adhered to and particular attention must be paid to providing extra ties around openings and to assuring that the topmost row of ties is installed and is adequate. Figure 5.10 illustrates some specific points requiring attention.

- Lintels over windows, doors, or other openings must be entirely contained within the veneer and not attached to the backup wall or structure. If vertical movement joints coincide with one end of the lintel, provision to allow movement must be incorporated as shown on the design drawings. Figure 5.11 contains some discussion of different approaches.

- The backup wall must be anchored to the structure at its base and sides or top, but must also permit horizontal and vertical movement joints to function as intended. This aspect will be covered in more depth in Chapters 6 and 7 for CM and SS backup walls.
- Brick must satisfy Canadian standards[16,17] and should be chosen from those with proven service records. Use of glazed brick is not recommended.

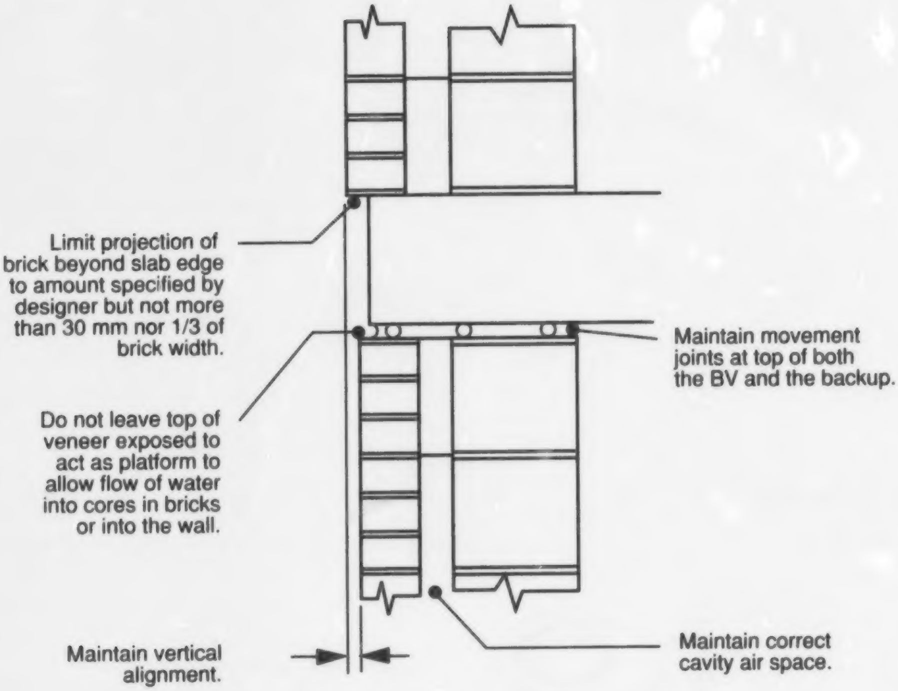
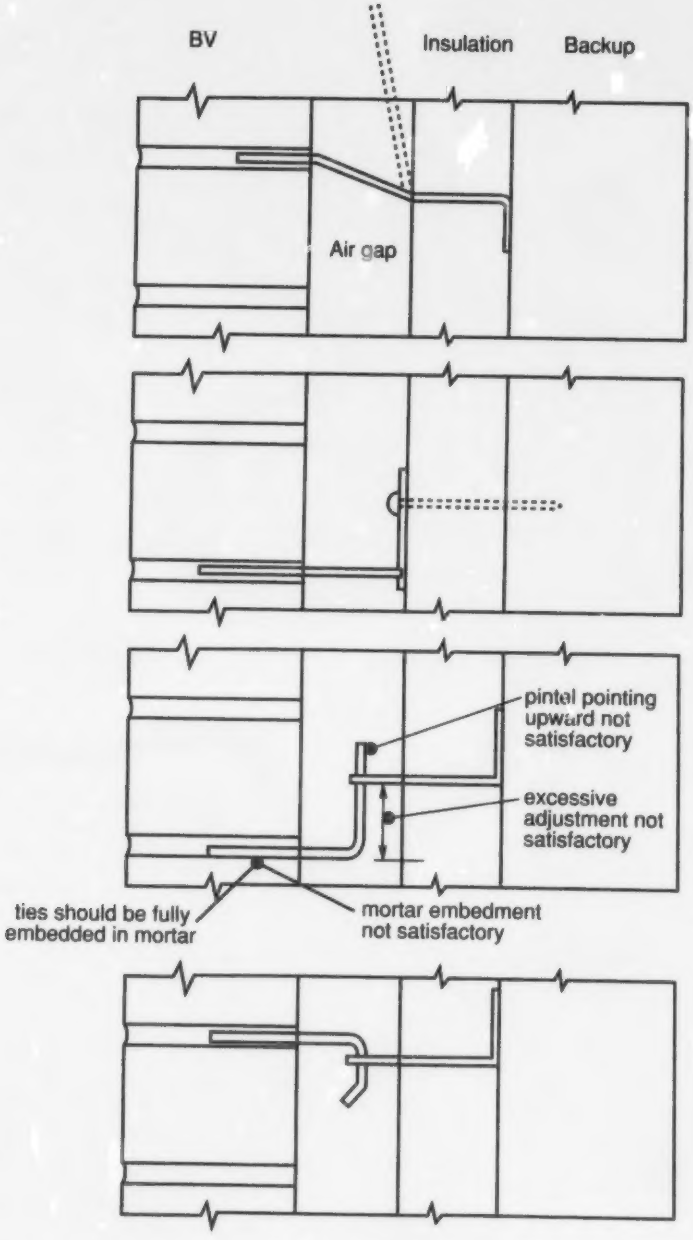

Limit projection of brick beyond slab edge to amount specified by designer but not more than 30 mm nor 1/3 of brick width.
Do not leave top of veneer exposed to act as platform to allow flow of water into cores in bricks or into the wall.
Maintain vertical alignment.
Maintain movement joints at top of both the BV and the backup.
Maintain correct cavity air space.

Figure 5.8 Illustration of tolerance-related issues for construction of BV on floor slabs


BV
Insulation
Backup
Air gap
pintel pointing upward not satisfactory
excessive adjustment not satisfactory
ties should be fully embedded in mortar
mortar embedment not satisfactory

Ties should not be bent out of place during construction. Damage to the tie or misalignment when bent down may substantially reduce capacity.

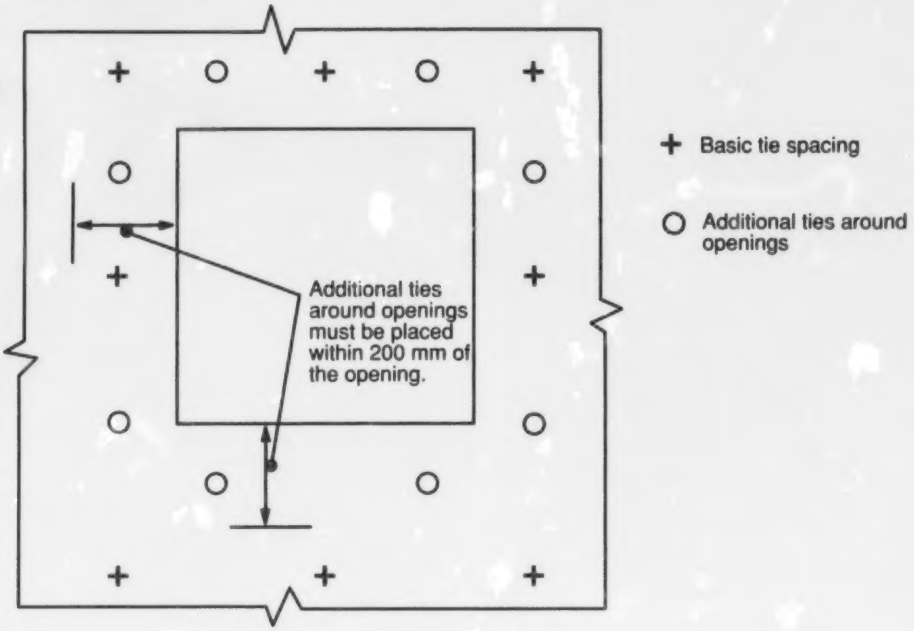
For use of ties intended to be mounted on insulation or other wall coverings, data must be available to demonstrate satisfactory performance.

Adjustable ties should not be able to disengage under extreme load/displacement. In this case the pintel should point down. The adjustment should be minimized.

Satisfactory construction detail showing proper tie embedment, small adjustment, and pintel pointing down.

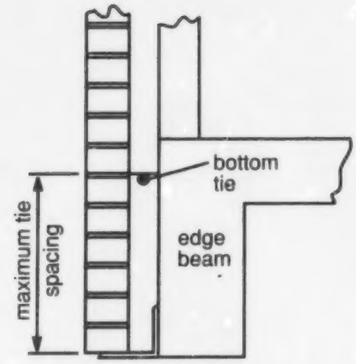
Figure 5.9 Construction concerns regarding tie placement

a) Placement of additional ties around openings


+ Basic tie spacing
O Additional ties around openings

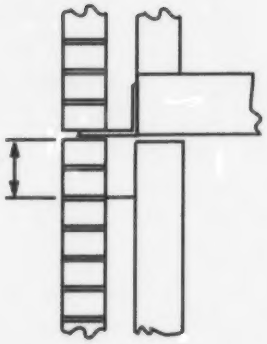
Additional ties around openings must be placed within 200 mm of the opening.

b) Positioning of the bottom tie


bottom tie
edge beam
maximum tie spacing

Where deep-edge beams are present, the bottom tie may have to be attached to the floor system in order to satisfy maximum spacing limitations.

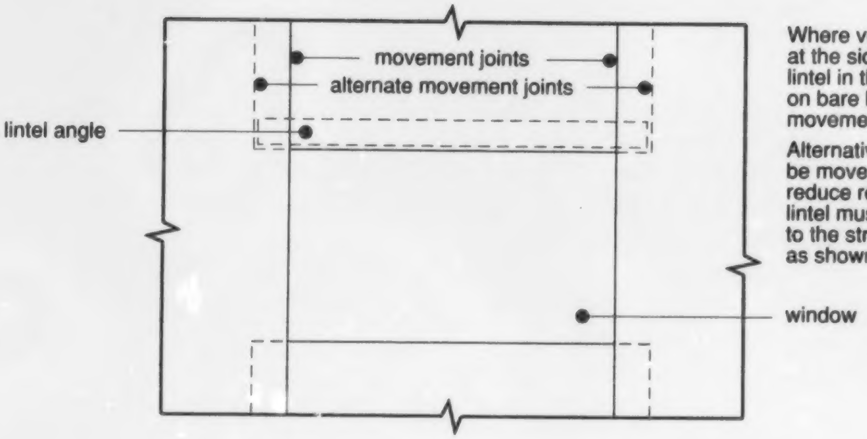
c) Positioning of the top tie



Maximum distance of top tie from top of veneer is half the normal maximum spacing.

The top tie must often transfer the largest force to the backup wall. It is therefore particularly important that this tie be positioned properly and in an undamaged condition.

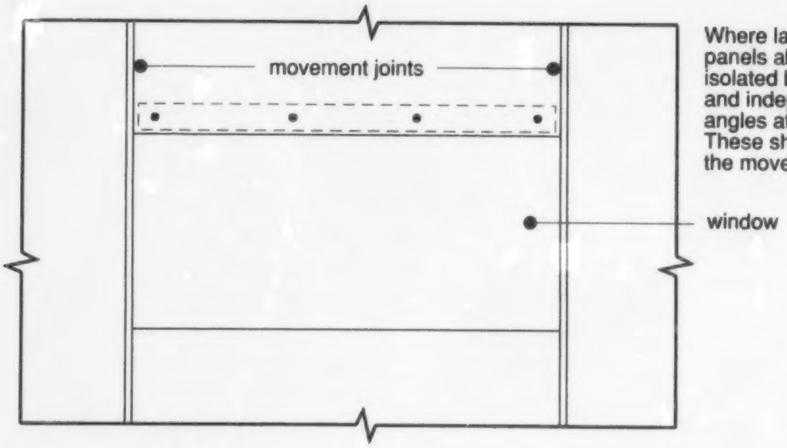
Figure 5.10 Special considerations for tie placement



Where vertical movement joints exist at the sides of an opening, the lintel in the veneer should be laid on bare bricks to allow horizontal movement more readily.

Alternatively, the movement joint could be moved to the end of the lintel to reduce resistance to movement. The lintel must not be attached directly to the structure or backup wall, except as shown below and in Figure 5.3.

a) Lintel support as part of the veneer



Where large openings occur, veneer panels above these openings may be isolated by vertical movement joints and independently supported by shelf angles attached to the structure. These shelf angles must not cross the movement joints.

b) Lintel serving as a shelf angle for independent support of veneer over openings

Figure 5.11 Details for support of veneer over openings

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[13] Canadian Standards Association, CSA Standard A179, *Mortar and Grout for Unit Masonry*, CSA, Rexdale, 1976.

[14] Water Penetration Study Committee, *Recommended Details and General Information to Overcome Water Penetration and Vapour Movement in Exterior Masonry Wall Systems*, Borough of Scarborough.

[15] Brick Institute of America, *Brick Veneer New Construction*, BIA Technical Notes on Brick Construction, 28 July 1986.

[16] Canadian Standards Association, CAN/CSA-A82.1-M87, *Burned Clay Brick (Solid Masonry Units Made from Clay or Shale)*, CSA, Rexdale, 1987, 17 pages.

[17] Canadian Standards Association, CAN3-A82.2-M1984, *Methods of Sampling and Testing*, CSA, Rexdale, 1984.

# CHAPTER 6

# BV/CM SYSTEM: STRUCTURAL REQUIREMENTS

## 6.1 INTRODUCTION

Code provisions for the design of brick veneer with concrete-block backup walls are contained in CSA Standard CAN3-S304 for loading conditions discussed in Section 3.3. The application of these provisions requires some interpretation and this plus perhaps lack of a clear understanding of behaviour of masonry by some designers has led to a variety of design and construction details, some of which have not performed well. What is often missing is a clear definition of the system and the assumptions involved in the design. This is required so that design decisions or construction techniques which may violate the intended behaviour can be identified.

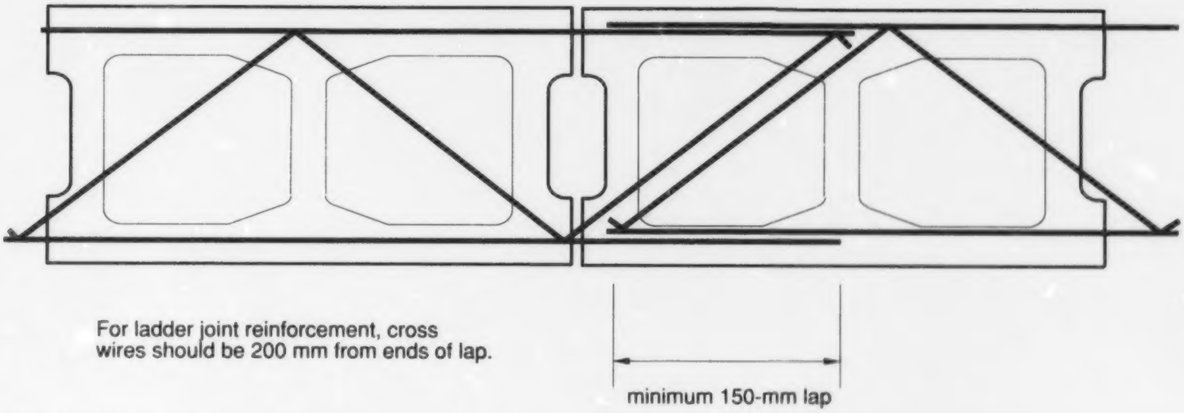
## 6.2 CM BACKUP

Specifications for blocks are issued by the Canadian Standards Association.[1]

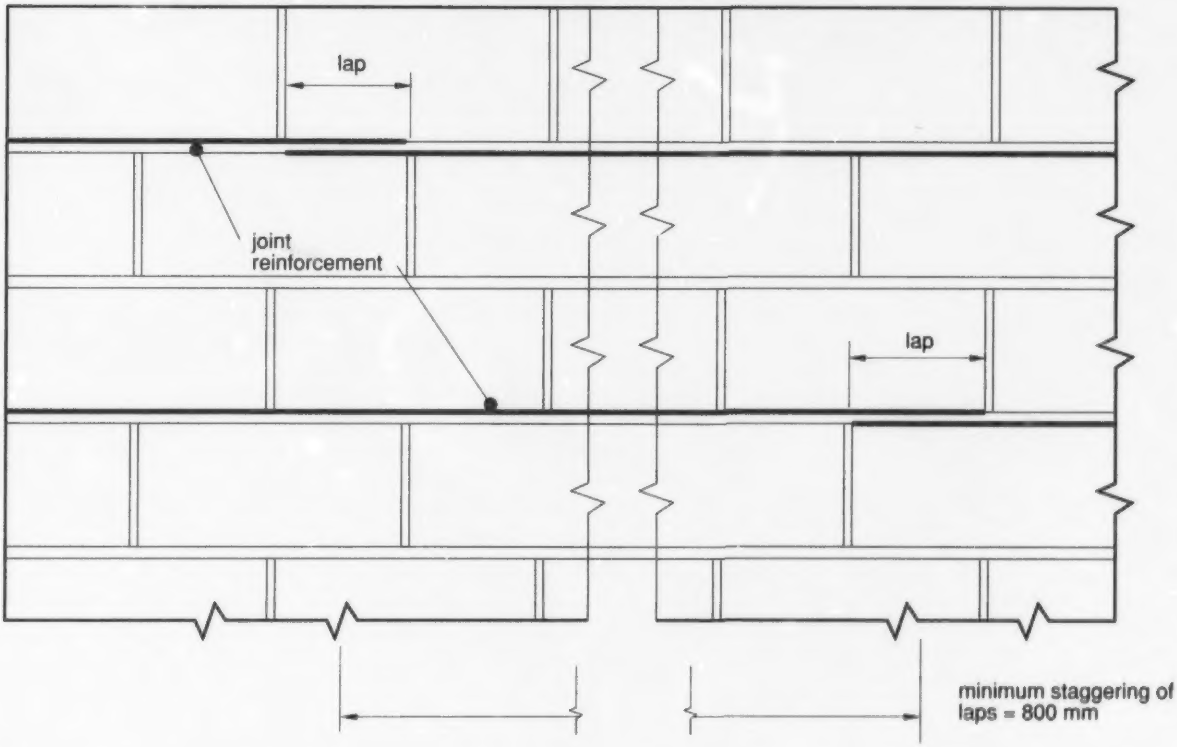
The CM backup wall must be designed to resist lateral loads, but often this is done using the empirical rules for plain masonry of Section 6 of CAN3-S304, where height-to-thickness limits of 20 are specified with minimum thicknesses of 140 mm and 190 mm depending on whether the block is a solid or hollow unit. Users of this design method must ensure that the above limitations are satisfied. Otherwise plain CM backup may be designed by engineering analysis to withstand the wind pressure or seismic load. It may be designed spanning vertically, horizontally, or both, depending on support conditions and arrangement of openings. It should be noted that support on more than two sides can provide a much stronger backup wall which will not fail at formation of the first crack.

In some cases, it is desirable or, as is the case for seismic zones 4 or greater, necessary to reinforce the block backup. In seismic zones 4 or greater, the minimum amount of steel of 0.0010 $A_g$ must be placed in two directions at a spacing not exceeding 1.2 m and with a distribution of at least one-third of the steel in any direction. In seismic zones 3 or less, the minimum of 0.0005 $A_g$ may all be placed in one direction provided that it is continuous between lateral supports, located to adequately reinforce the wall against lateral loads, and spaced so as not to exceed 400 mm where joint reinforcing is used. Typically, additional reinforcement equivalent to at least a 15-mm bar must be introduced around all openings.

The use of joint reinforcement is the simplest construction method but requires special attention to proper lapping and staggering of laps. As shown in Figure 6.1, minimum laps of 150 mm and staggering of laps by a minimum of 800 mm in successive courses are recommended. Also, if the joint reinforcing is being relied upon to resist lateral load in horizontal bending, the walls must be supported and anchored at the ends. Alternatively, bond beams at the top and at mid-height of the wall (1.2-m spacing) may provide a convenient form of construction where both the reinforcement and the end anchors can be grouted in as construction progresses.


For ladder joint reinforcement, cross wires should be 200 mm from ends of lap.
minimum 150-mm lap

a) Minimum lap for splicing joint reinforcement


lap
joint reinforcement
lap
minimum staggering of laps = 800 mm

b) Minimum requirements for staggering of laps for splicing joint reinforcement

Figure 6.1 Requirements for placing joint reinforcement

At vertical control joints, it is recommended that joint reinforcement be discontinuous in order to allow unrestricted movement. Where there is a structural requirement to transfer horizontal shear across the joint or to the supporting structure or to the continuing backup, the device should be detailed to avoid developing in-plane forces. Figures 4.8 and 6.2 contain examples of such details.

The use of vertical reinforcement has many structural advantages, not only because the floor to ceiling span is usually much smaller than the horizontal span, but also because openings in the wall can interrupt horizontal bending. However, such construction must be carried out with care. Typically the reinforcing rod must be placed at the time the first course is laid and grouted in place using low-lift grouting as construction progresses. To avoid problems with placing blocks after the vertical reinforcement, three alternatives to placing reinforcement in the cells of normal stretcher units are suggested:

1. Commercially available A- or H-blocks can be used so that the open end can be used for the reinforcing bar to be grouted in as shown in Figures 6.3 (a) and 6.3 (b).
2. The vertical reinforcement can be located in the cell at the head joint if created by frogged-ended blocks, with the blocks laid in a stack pattern as illustrated in Figure 6.3(c). Use of a stack pattern requires horizontal reinforcement, and since there are continuous, vertical weak planes, there is greater likelihood of cracking which can be controlled, but not prevented, by horizontal joint reinforcement or bond beams.
3. Where A- or H-blocks are not available and a stack pattern is not acceptable, it is suggested that the end webs of blocks be knocked out or preferably cut out. This again allows for easy placement of the block around the reinforcing bar.

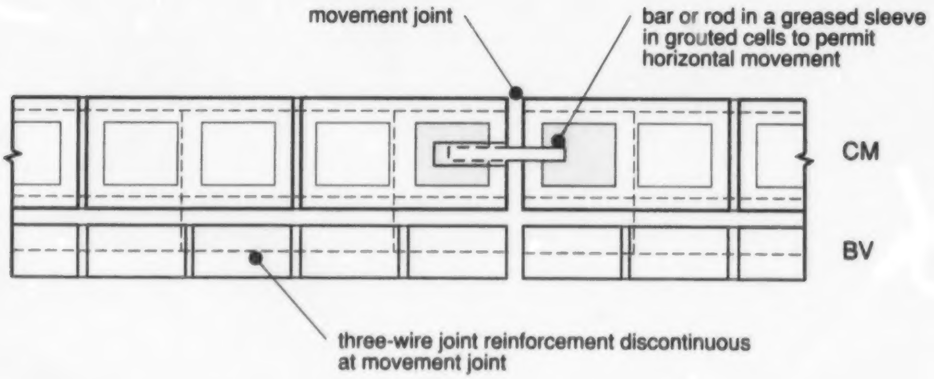
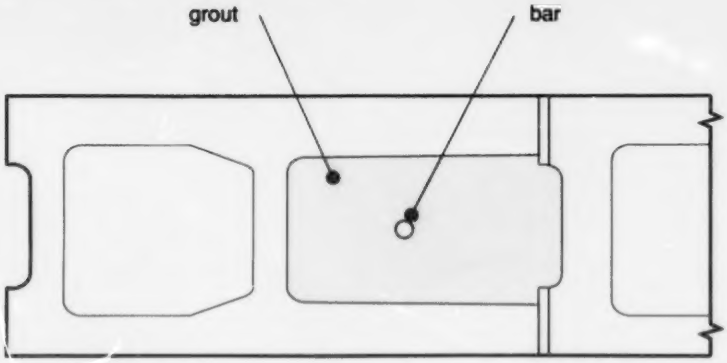
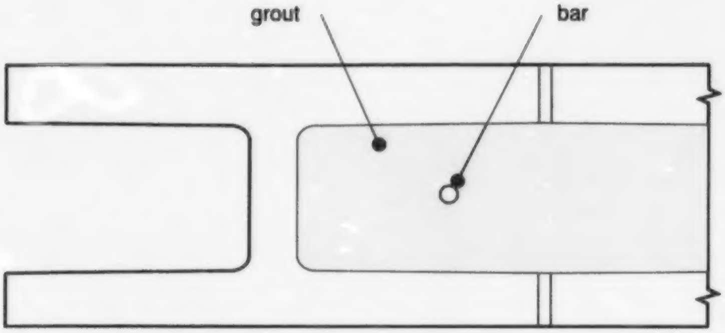

movement joint
bar or rod in a greased sleeve in grouted cells to permit horizontal movement
CM
BV
three-wire joint reinforcement discontinuous at movement joint

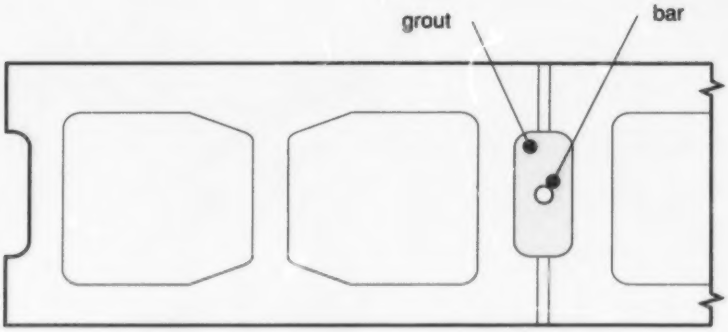
Figure 6.2 Shear transfer detail of movement joint in CM



a) Use of A-block with open-end for ease of placing block around reinforcement.



b) Use of H-block with opened ends for ease of placing block around reinforcement.
(Note: This results in a fully grouted wall.)



c) Use of head joints and stack pattern for placing reinforcement.

Figure 6.3 Alternatives for placement of vertical reinforcement in CM

For any of the above methods, grouting the bar in place in the top block is a difficult step because the distance between the top of the block and the floor slab or spandrel beam will be only a few millimeters. Therefore this last course should be grouted using either dry packing of grout or mortar. While it is important to completely fill the cell which houses the bar, it is also important not to overfill or, otherwise reduce the effective size of the movement joint shown in Figure 6.4. Where vertical reinforcement is used, the wall must be anchored at the top and bottom as will be discussed in the next section.

Although the CM backing wall may be built from either the inside or outside, it is important that the mortar joints be tooled to improve airtightness and ability to shed surface moisture as depicted in Figure 6.4. Lintels over openings may be made using bond beams, steel sections, or precast concrete. Except where the wall is loadbearing, the load to be designed for is the weight of the blocks within a 45° triangle above the lintel as shown in Figure 6.5.

## 6.3 ANCHORAGE TO FRAME

The CM backup wall must transfer lateral loads to the supporting structure or, conversely, connections to the supporting structure must provide support for the wall. The location of the connections must be consistent with the direction of bending resistance.

If the structure is a moment-resisting frame, the CM backup should allow for inter-storey drift up to span/500, and the vertical joint should be kept free of material which could transfer load.

Therefore, if the wall is anchored along its ends, the anchors must be able to transfer out-of-plane shear but not offer resistance to in-plane horizontal movement of the frame. For stiffer-shear wall structures, common practice is to build block walls in tight to the support structure in which case a vertical mortar joint will normally be used. However, because of shrinkage and general building movement, where the ends of the wall are required to be supported, mechanical anchors, such as dovetail anchors or dowels mechanically anchored, should be used to provide positive connection as shown in Figure 6.2.

For unreinforced CM walls, it is normally satisfactory to bond the wall to the floor using a mortar bed and to support the top of the wall using clip angles as shown in Figure 6.6. The common mistake of wedging or filling the movement joint with mortar prevents the movement and may result in damage to the wall and/or the structure. Details such as clip angles must be used to allow vertical deflection of the floor. Also, where the structure is a moment-resisting frame, the top support must allow in-plane horizontal movement of the frame, otherwise the wall will become loaded in shear. When the frame deflects, distress may ensue as indicated in Figure 6.7.

For vertically reinforced blockwork, the bottom of the wall should be anchored by dowels coinciding with the vertical reinforcement. At the top, the free vertical movement can again be accommodated by clip angles. The clip angles should be located at the positions of the grouted bars.

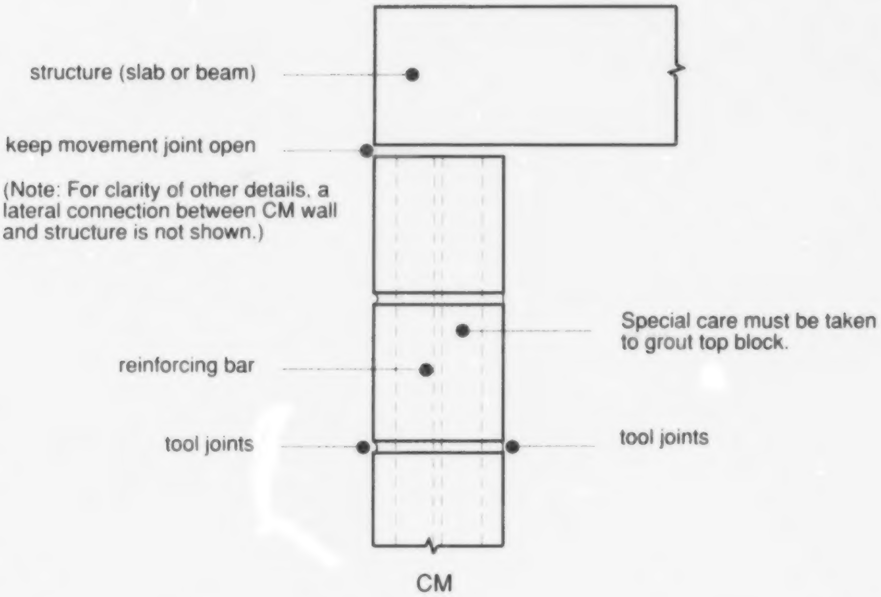

structure (slab or beam)
keep movement joint open
(Note: For clarity of other details, a lateral connection between CM wall and structure is not shown.)
Special care must be taken to grout top block.
reinforcing bar
tool joints
tool joints
CM

Figure 6.4 Movement joint requirements between structure and CM backup

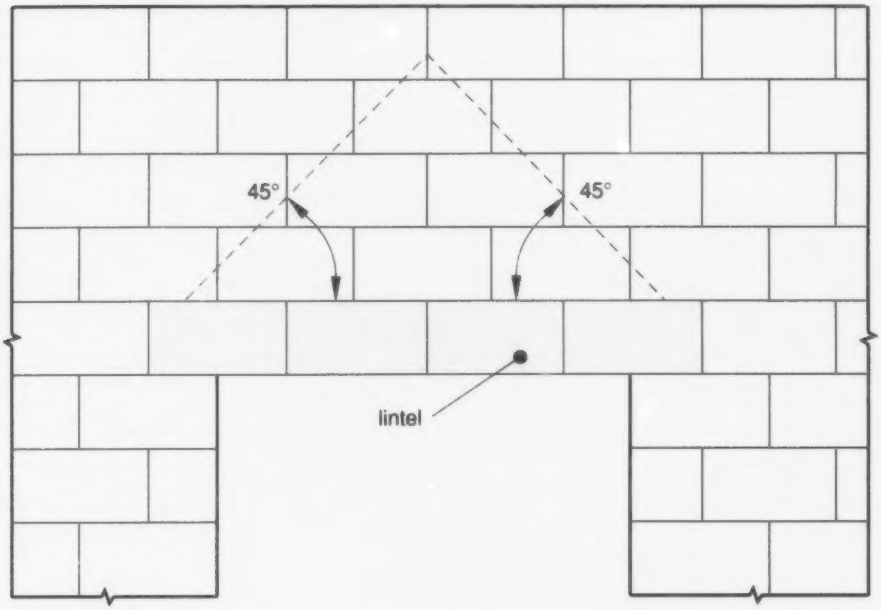
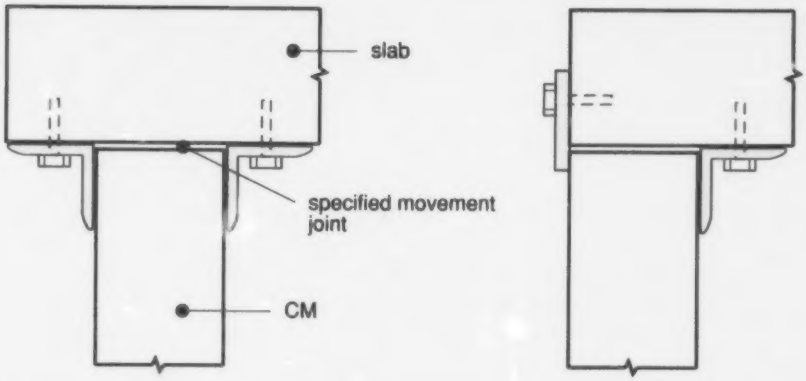
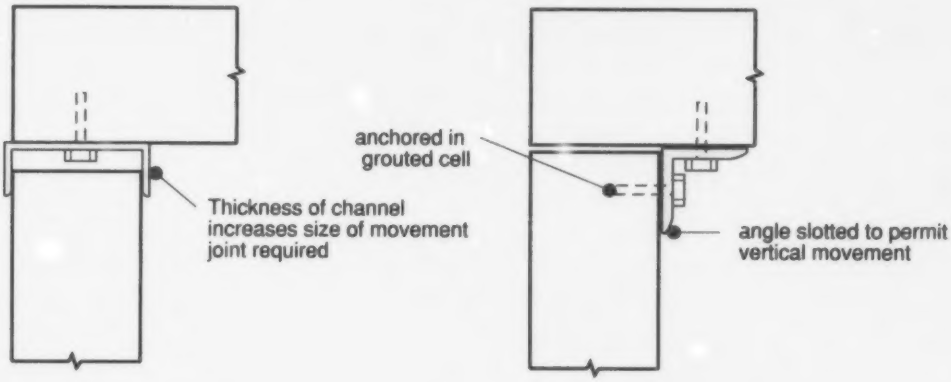

45°
45°
lintel

Figure 6.5 45° Lines defining loading on lintel above opening


slab
specified movement joint
CM

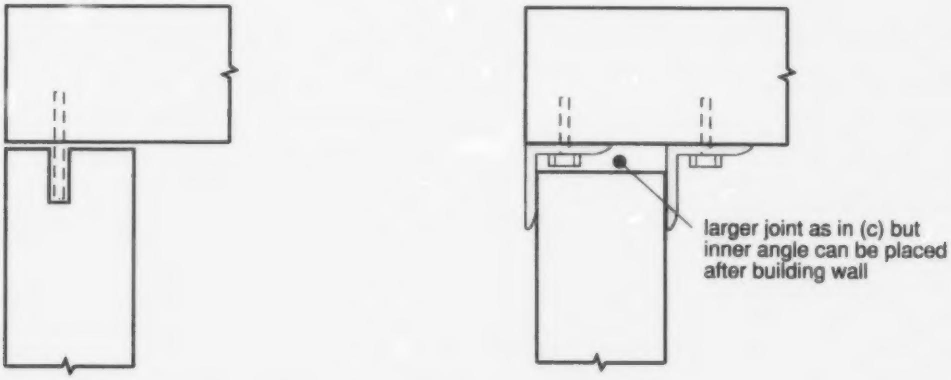
a) Clip angles (easy to position but requires wall to be located inward from edge of slab)

b) Clip angle and clip plate (allows wall to be located at edge of slab ... potential conflict with positioning on shelf angle)


Thickness of channel increases size of movement joint required
anchored in grouted cell
angle slotted to permit vertical movement

c) Use of channel (must be positioned prior to placing block-cold bridge through wall)

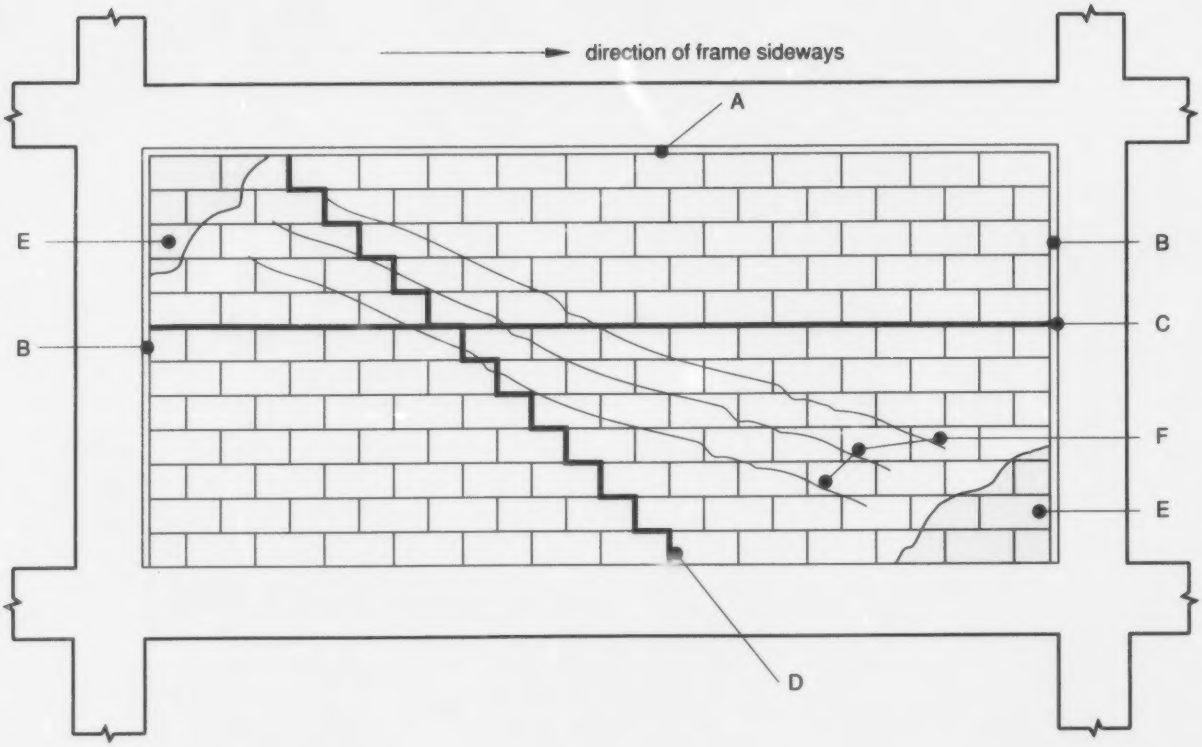
d) Slotted angle (correct tightness of anchor bolt required to allow movement)


larger joint as in (c) but inner angle can be placed after building wall

e) Anchor bolt in a sleeve (some difficulty with positioning and providing grout support around sleeve)

f) Use of two angles

Figure 6.6 Methods of supporting top of CM backup walls



a) Filled horizontal joint or mechanical connection will load wall in shear as frame sways sideways resulting either in slip along a bed joint (C) or in diagonal cracking (D).

b) Filled vertical joints will cause bearing of the frame against the wall as it sways sideways. This can cause either of the shear cracking modes shown above or local crushing in the corners (E). Diagonal cracking from corner to corner is also possible (F).

Figure 6.7 Potential distress of infill CM wall when movement joints ineffective

## 6.4 *BRICK VENEER*

For typical 90-mm brick veneer, the maximum lateral load shared by the veneer before cracking has been found to be between 10 to 30 percent for 20- and 15-cm concrete block backup depending upon the relative moments of inertia and moduli of elasticity. Therefore, before the block wall's cracking due to flexural loads, the tensile bond stresses in the brick veneer will be quite low. However, for reinforced blockwork where cracking must occur to develop the design tension in the reinforcement, the backup wall will be much more flexible and there is greater likelihood of flexural cracking of the brick veneer. A conservative estimate of the percentage of load shared by the veneer can be calculated by using the moment of inertia of the transformed area of the cracked section for the block and the moment of inertia of the uncracked brick veneer. The ratio of the EI value of the BV to the sum of the EI of the BV plus CM will give the proportion of load carried by the veneer. (See Section 5.3 for a more complete discussion.) More accurate results can be obtained using an analysis which accounts for tie stiffnesses, support conditions, and extent of cracking in the backup wall.

If both the BV and the CM backup are built at the same time, it is possible to use the cross wires of ladder or truss three-wire joint reinforcement as ties, where one wire is embedded in the brick veneer as shown in Figure 6.2(b).

Use of the joint reinforcement as the tie system, where the veneer is built after the block wall, can be done but is not favoured from a construction point of view because of one's having to build up under the protruding wire and forcing the wire down in the mortar bed so that the next layer of brick can be placed. Similarly, use of rigid ties, such as Z ties or rectangular ties, is recommended when they can be placed in the mortar bed on both wythes at the same time.

Use of rigid ties, where the veneer is constructed later, places rather exacting demands on matching the coursing and generally should be avoided. For hollow concrete masonry, the designer must specify details for the proper anchorage of the tie in the mortared area of the bed joint. Construction must also ensure that proper anchorage is achieved.

## 6.5 KEY CONSTRUCTION REQUIREMENTS

From the preceding discussion of BV/CM structural requirements and other considerations, the following key requirements for construction of the system stand out:

- Concrete block should be kept dry to minimize shrinkage of the concrete masonry.
- Specified mortar proportions must be followed to achieve proper masonry bond.[2]
- Sufficiently fluid grout of about 250-mm slump is to be used and vibrated/puddled to assure complete filling of voids to be grouted.
- Specified placement of all vertical and horizontal reinforcement is essential to achieve design strength and, in the case of cover, durability. This means proper splicing of reinforcing bars, lapping of joint reinforcement (typically 150 mm) and staggering of laps (typically 800 mm) are all essential.
- Proper tie placement is vital to the long-term performance of the wall system. Of utmost importance are the anchorage of ties and avoidance of tie damage such as kinks which drastically reduce capacity.
- Proper wall anchor placement is essential to the safe support of the backup to resist wind and earthquake loads.
- Movement joints must be kept clear of all materials which can inhibit free movement. As discussed in Chapters 4 and 15, the consequences of improperly constructed movement joints can be very severe.
- Unless specifically shown on drawings, joint reinforcement should not be continued across movement joints.
- Good masonry workmanship, including full filling and tooling of mortar joints, is required since the BV/CM wall system is exposed to demanding environmental conditions of loadings and moisture for many decades.[3]
- No materials may be substituted without approval of the designer. In particular, ties must have the specified corrosion protection.
- Corrosion protection must not be damaged during construction.

## REFERENCES

[1] Canadian Standards Association, CAN3-A165 Series-M85, *CSA Standards on Concrete Masonry Units*, CSA, Rexdale, 1985, 51 pages.

[2] Drysdale, R.G., and Gazzola, E.A., *Influence of Mortar Properties on the Tensile Bond Strength of Brick Masonry*, Proceedings of 7th International Brick Masonry Conference. Melbourne, Australia, 1985.

[3] Canadian Standards Association, CAN3-A371-M84, *Masonry Construction for Buildings*, CSA, Rexdale, 1984, 50 pages.

[redacted]

# CHAPTER 7

# BV/SS SYSTEM: STRUCTURAL CONSIDERATIONS

## 7.1 INTRODUCTION

The use of steel stud construction as the structural backup wall for brick veneer cladding has gained substantial popularity as an economical and lightweight form of construction. However, the rapid development and use of this wall system preceded engineering research on several aspects of design. Authoritative design and construction practices developed to protect the safety and investment of the public have not been widely adopted and for some subject areas do not yet exist. Lacking comprehensive design guidelines, typically designers with specialist knowledge and experience in design with cold-formed steel are required to provide proper design and detailing. Examples of distress, often representing extremes of poor construction quality or design details, have served to focus attention on this topic in North America. Therefore there has been pressure to provide authoritative information and guidance for designers and contractors. The manufacturers of steel stud wall components, tie manufacturers, insulation, and air and vapour barrier companies have all responded to the challenge, and there have been many new ideas and products introduced into this field in the past few years. In addition, through such associations as the CSSBI, relevant information is being made available.[1]

This Advisory Document has taken the most recently available information and through discussions with experts in the industry and other technical advisors, a basis for the structural design has been derived, and alternatives have been presented. Where possible, specific recommendations have been made, whereas in other places, the decision on alternatives has been left to the designer.

Reference should be made to Chapters 3, 4, and 5 where design information common to both BV/SS and BV/CM has been provided. In this regard it is important to keep in mind that comments and recommendations concerning the structural design of the SS backup wall relate specifically to its use as support for brick veneer and may not be appropriate where other cladding systems are used.

## 7.2 DESCRIPTION OF THE STEEL STUD WALL SYSTEM

The typical components of a SS backup wall system are shown in Figure 7.1, where the steel stud is the basic member which must have top and bottom tracks to support or frame the wall. In most designs some form of bracing or internal bridging is required to develop the flexural strength of the studs (i.e., prevent flexural torsional buckling). In the *stick-built* construction method, components are normally connected by self-drilling short metal screws.

However, welding has been used for some buildings, in particular where the SS wall system is prefabricated. Figure 7.2 illustrates the location of welding to provide an effective connection while permitting welding from one side.

The structural design of a SS backup wall must give attention to its attachment to the structure, including allowance for movement and differential movement of both the structure and the backup wall. The effects of and interactions with sheathing materials also must be taken into account, as must the tie loads and influence of the brick veneer on the distribution and magnitudes of tie loads.

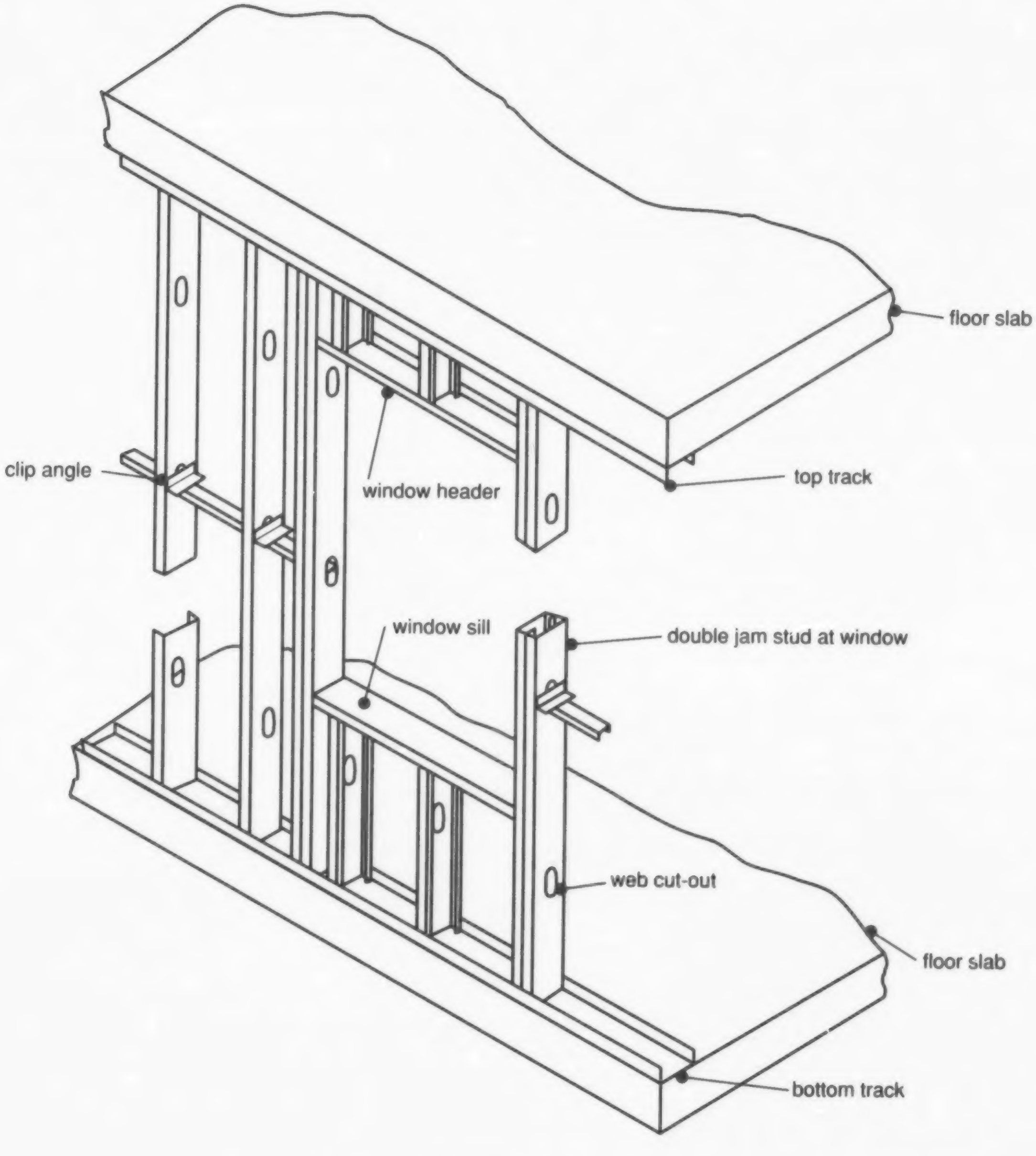

floor slab
clip angle
window header
top track
window sill
double jam stud at window
web cut-out
floor slab
bottom track

Figure 7.1 Illustration of components of SS backup walls

Although welding of metal parts as thin as 0.7 mm is allowed (see CSA's CAN3-S136-M84 *Cold Formed Steel Structural Members*) for structural connections where certified welders are employed, a minimum of 18 gauge (1.2 mm) is normally recommended for field welding.

Weld locations must be touched up to restore corrosion resistance in these areas.

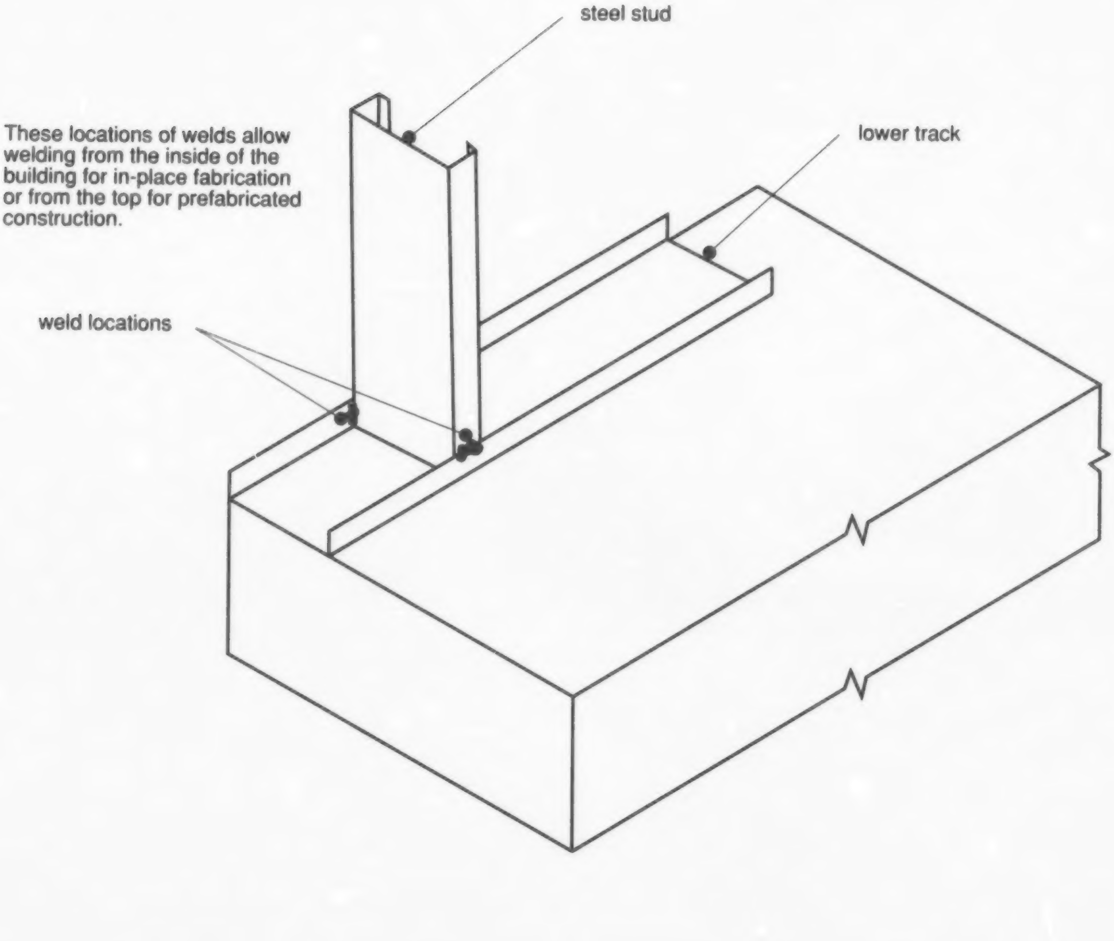

steel stud
lower track
These locations of welds allow welding from the inside of the building for in-place fabrication or from the top for prefabricated construction.
weld locations

Figure 7.2 Welded connection of steel stud to track

## 7.3 DESIGN OF THE STEEL STUD

The structural design of steel studs for wind or other lateral forces is normally governed by

- maximum (midspan) bending moment;
- specified out-of-plane deflection limit; and
- shear and web crippling.

In this regard most manufacturers' information is based on the assumption that full lateral support exists on both flanges of the studs (i.e., no flexural-torsional buckling can occur). Also, web crippling due to concentrated loads or reactions is frequently not checked. Therefore, as will be discussed later, both of these factors must be included as part of the design process. [2,3,4,5,6,7]

Although tests have shown that drywall or other sheathing materials screwed to studs can result in composite action, repeated cycles of loading rapidly diminish the benefit of this composite action through enlargement of the screw holes or other loosening. Also, particularly on the outside of the backup wall, possible wetting would substantially reduce the ability of drywall to resist bending. Furthermore, horizontal joints between drywall sheets result in lengths of stud without potential for any composite action. Therefore, it is recommended that such screw-attached sheathing as drywall not be relied upon either for flexural capacity or for increased section stiffness to reduce calculated deflections.

The following specifier note is from the *Lightweight Steel Framing Manual* CSSBI 50M-1987, August 1987 [8] and is also adopted in this Advisory Document as sound design practice.

Some sheathing materials such as gypsum drywall may lose their structural integrity when subject to a moist environment or when subject to a sufficient number of load cycles. Such materials may not be suitable to act as structural bracing. If the sheathing is utilized as bracing, it is standard practice in the industry to provide sufficient steel bridging to align members during erection and to provide the necessary structural integrity during construction as well as in the completed structure."

Therefore metal bridging is required to assure development of the flexural resistance of the studs. This will be discussed in more detail in Section 7.5.

Structural analyses[9,10,11,12] and tests [13,14,15] have shown that brick veneer will significantly reduce the bending in the steel studs before cracking of the veneer. However, unless the brick veneer is specifically designed and inspected to act as a structural member, the designer of the SS backup wall must assume that the BV cracks and that the full wind or seismic loading is resisted by the steel studs. In addition, the interaction of the BV with the SS backup wall can result in very non-uniform distributions of tie loads. As is shown in Figure 7.3, for a representative BV/SS wall before cracking, the top tie transfers a high fraction of the lateral load regardless of whether the load is on the BV or SS part of the wall.

After cracking of the veneer, the tie(s) nearest the crack then transfer(s) most of the load. The existence of these highly concentrated tie loads not only affects the design of ties but also must be accounted for in the design of the studs.

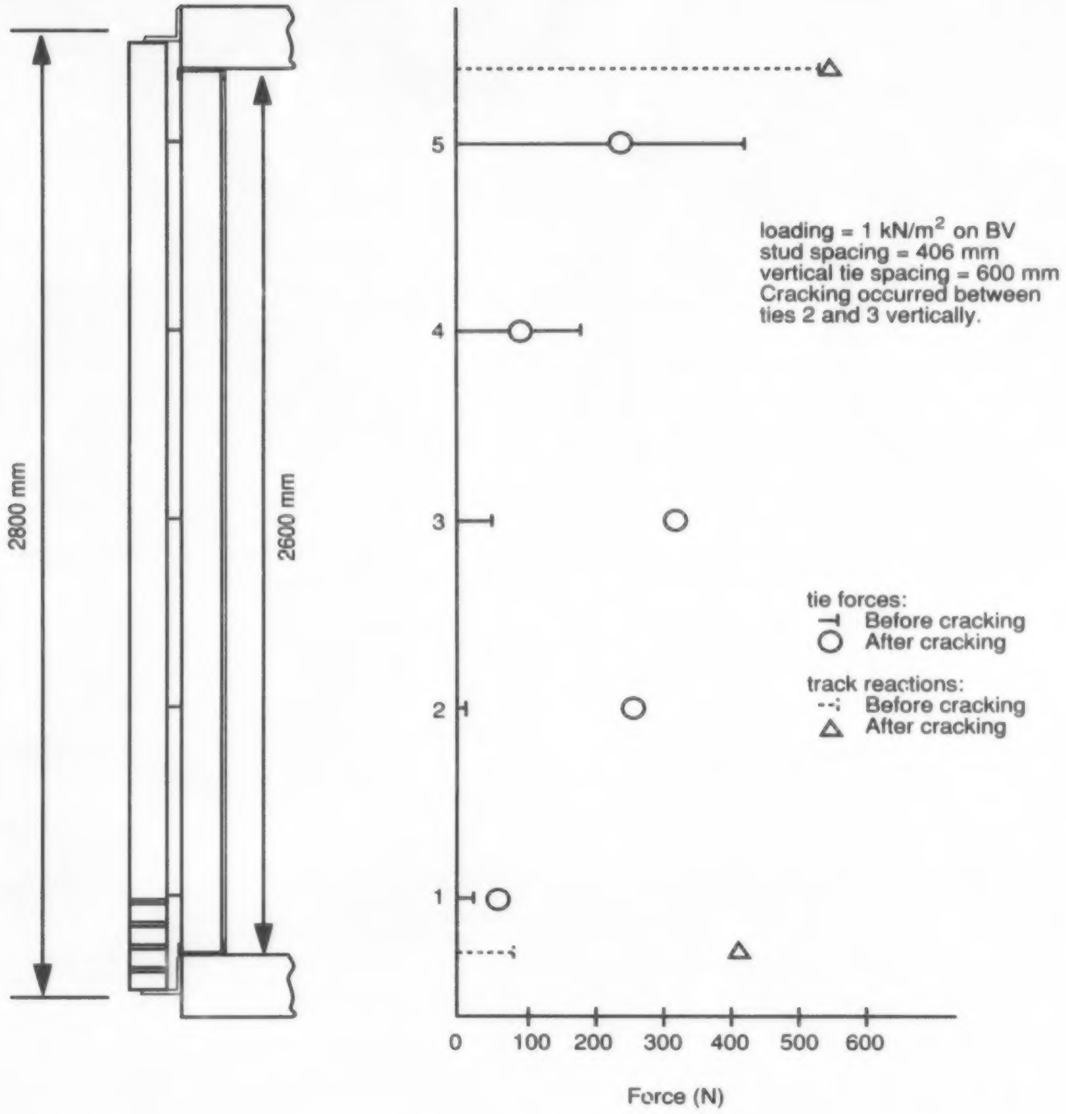


Figure 7.3 Representative distributions of tie and track forces

The following comments relate to the key design criteria identified for SS members.

### *MAXIMUM BENDING MOMENT*

Unless manufacturers provide certification that tests or analysis confirm that the full yield moment capacity of a section can be developed, designers must check this by using the provisions of CAN3-S136-M84 (*Cold Formed Steel Structural Members*).[16,17]

Where perforated webs exist, the influence of the openings on section properties and member behaviour must be accounted for. As mentioned above, the SS wall must be designed to resist the full lateral load. In this regard, the influence of eccentric tie loads and the concentrated loads from ties must be accounted for both in terms of member behaviour (torsion) and local behaviour (web crippling) in the vicinity of the concentrated loads.

Steel studs require bracing in order to achieve the required moment capacity. This bracing can be in the form of sheathing (i.e., steel), or discrete bracing, or a combination of the two. Where discrete bracing is used, application of the full requirements for discrete bracing in accordance with Clause 8.3.2 of CAN3-S136-M84[18] may not be necessary. Deflection limits, rather than the full flexural beam strength, may control the design. Reduced bracing may be used if rational analysis or tests modelling the lateral and torsional effects and the effects of concentrated loads show that the required capacity can be achieved. In particular, bracing at intervals not greater than one quarter of the span length and provision of additional braces near zones of potentially highly concentrated loads, such as at top or centre ties, may not be required.

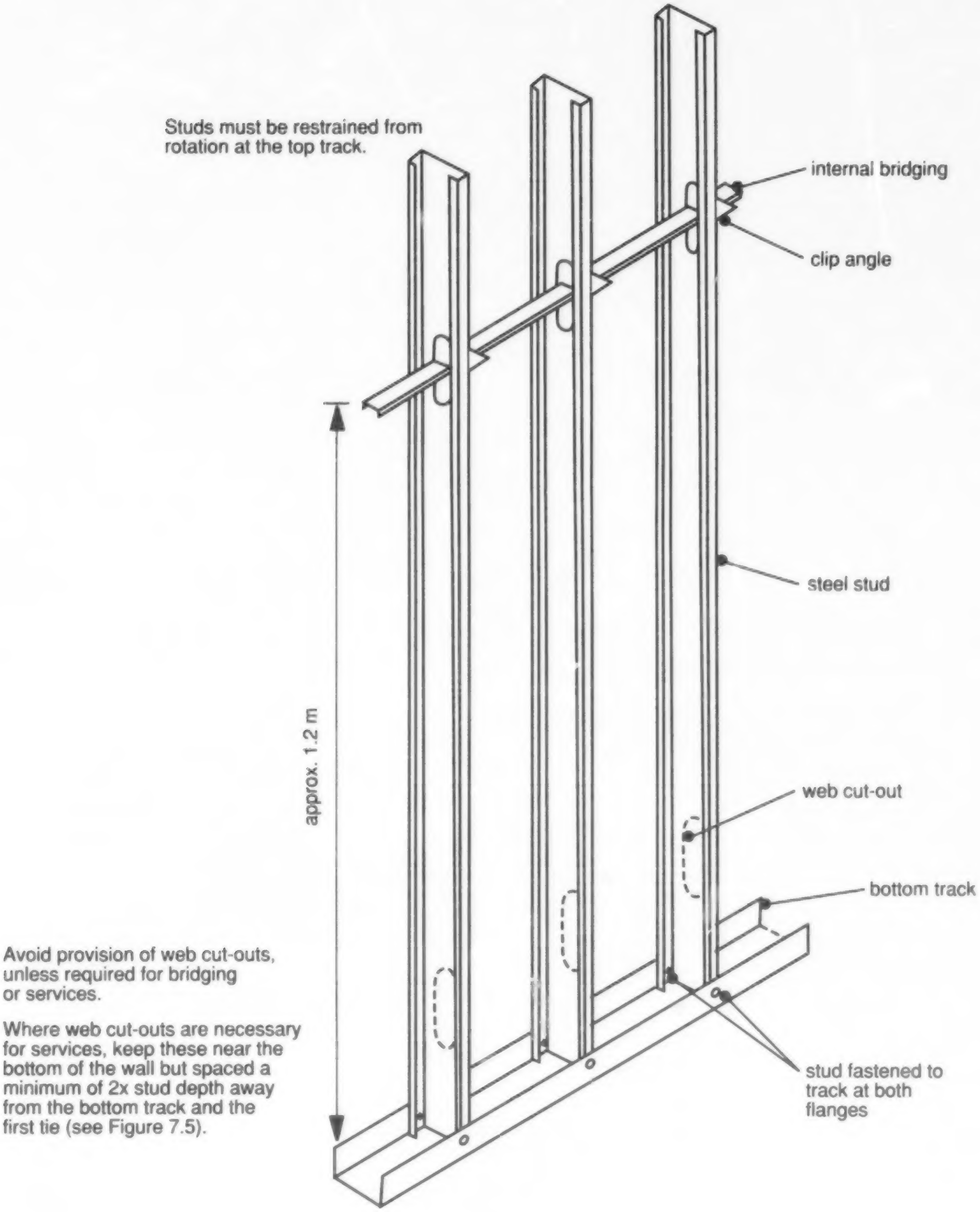
For studs spanning in the order of 2.6 m, tests[19] have shown that a mid-height brace and top and bottom restraint of both flanges (see Figure 7.4) may be sufficient. However, information pertaining to the particular tie used (eccentricity and degree of concentration of load) and section of the stud must be used in making this design decision.

Concentrated tie loads that induce web crippling near unreinforced cut-outs in the webs of studs must not be allowed, unless it can be demonstrated by test or analysis that the strength of the member is not compromised. While proper detailing may be sufficient to avoid this, it is recommended that cut-outs in webs be limited to locations where they are required for internal bracing.

Splicing of studs to extend the length should not be permitted.

### *DEFLECTION LIMIT*

Deflection is a serviceability limit state and therefore checked at specified, not factored, load levels. Where designers have chosen to adopt the criterion that allowable flexural tensile stresses in the veneer not be exceeded, deflection limits between span/2000 to span/3000 have been required. Aside from human sensitivity to deflection and cracking of interior finishes, the main criterion relates to the size of flexural cracking in the brick veneer. While a deflection of span/360 is currently the maximum acceptable value, other limits may be appropriate — a topic discussed in Chapter 10.


Studs must be restrained from rotation at the top track.
internal bridging
clip angle
steel stud
approx. 1.2 m
web cut-out
bottom track
stud fastened to track at both flanges

Avoid provision of web cut-outs, unless required for bridging or services.

Where web cut-outs are necessary for services, keep these near the bottom of the wall but spaced a minimum of 2x stud depth away from the bottom track and the first tie (see Figure 7.5).

Figure 7.4 Requirements for discrete bridging or bracing and for web cut-outs

The deflection limits are normally based on ignoring the contribution of the veneer and allowing the steel studs to resist the total lateral load. This is equivalent to considering the veneer to be cracked. As is discussed in Section 7.4, horizontal displacement of the SS wall due to local translation in the top or bottom tracks adds to the overall deflection.

### END SHEAR

To avoid premature failure of the stud at either the top or bottom, unreinforced web perforations should be kept away from the reaction points by a distance equal to at least two times the depth of the studs as shown in Figure 7.5. (The CSSBI[20] recommends a minimum distance of 300 mm from the end of the stud to the centreline of the first cut-out.) The method of attaching the studs to the tracks or frame can significantly influence shear or bearing capacity at the support points and therefore must be properly detailed.

Web crippling and torsional restraint must be taken into account as factors in the design capacity of the steel studs.[21] For flange connections, the steel stud should be attached to the track at both flanges and web crippling should be checked. As will be discussed in Section 7.4, other methods of support can be incorporated into the design.

### OPENINGS

It should be noted that at such openings as windows, the jam studs on either side of the opening will normally be required to carry equal portions of the lateral load transferred from the tributary area occupied by the window plus the stud wall areas above and below such openings.

While use of double studs is generally good design practice, large openings (i.e., more than three times the regular stud spacing) may require either a built-up member or more than one additional stud on each side of the opening. These studs should be tied together by straps or other means to facilitate load-sharing and where used, horizontal framing members above or below the opening should be capable of transferring the load to these studs. Track sections can also be used to strengthen jam studs. Figure 7.6 provides information on typical load distribution from window areas in walls.

Even where brick veneer is not used above and below openings, the fact that the steel stud wall tends to act as a unit means that the same design criteria should be used.

### CONCLUDING REMARKS

Use of 20-gauge steel studs has been common practice. However, there is evidence that the apparent economics of using this lighter section may, in fact, not be substantial in terms of the overall cost of the backup wall. Experience with handling and shipping of 20-gauge studs revealed that some have suffered some form of permanent damage before installation in the building. Such members must not be included in the construction. Alternatively, 18-gauge steel studs have been found to be much more resistant to handling conditions and very few have exhibited any form of distress.

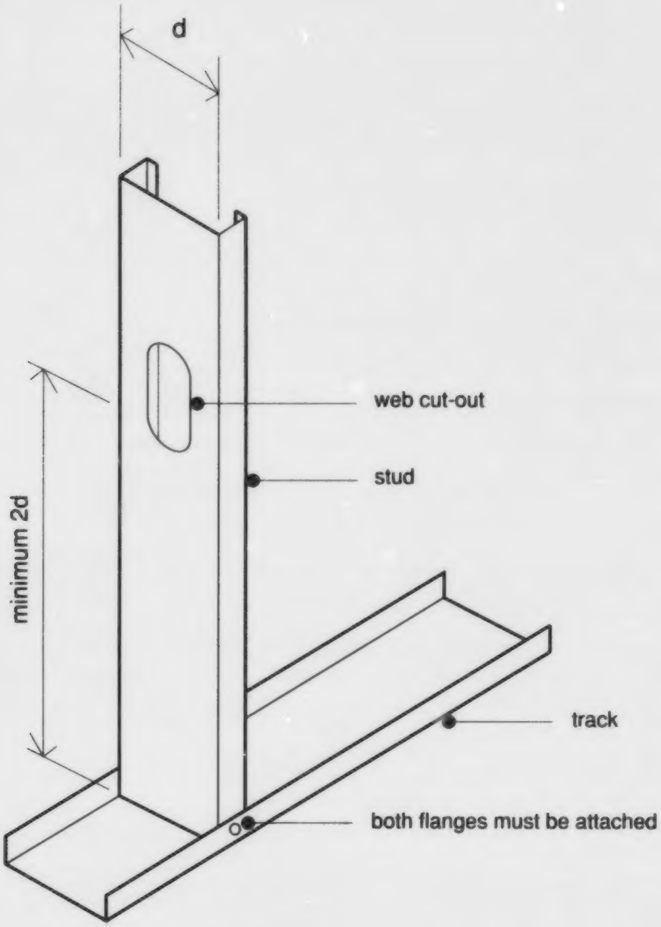
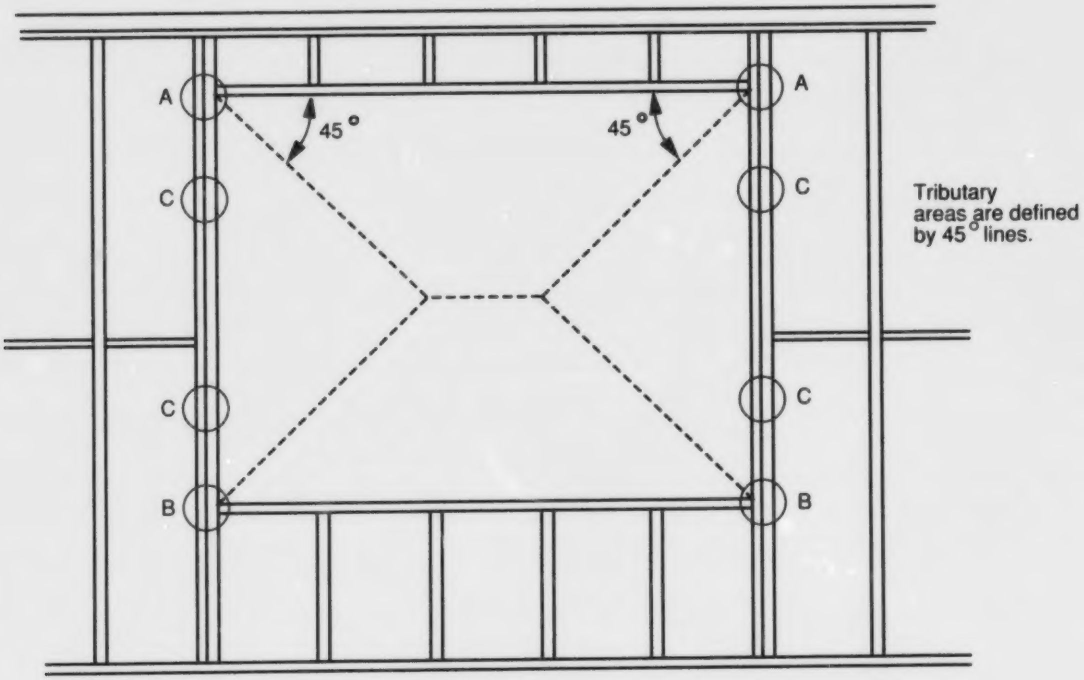

d
web cut-out
stud
minimum 2d
track
both flanges must be attached

Figure 7.5 Restriction on location of web cut-outs near reaction points



Tributary areas are defined by 45° lines.

Connection points A will each resist 25% of the wind load for the area above the window.

Connection points B will each resist 25% of the wind load for the area below the window.

If the window is supported along its sides, approximately 25% of the wind load from the window area will be concentrated at each point C.

If the window is attached top and bottom, points A and B will each carry 25% of the wind load from the window area.

If the window is supported uniformly around its perimeter, the wind load on the window can be distributed according to the tributary areas indicated by the dashed lines.

Figure 7.6 Load distribution from window areas in walls

BIA Tech Note 28B[22] recommends that 18-gauge be the minimum thickness for steel studs used as backup to BV walls. Following discussions with representatives of the steel stud manufacturing industry, this recommendation has been adopted in this Advisory Document. Principal reasons for this decision are:

- tests have shown that current bridging and bracing practices are much more effective for 18-gauge studs;
- effective screwed and welded connections are more easily achieved with the thicker-gauge material;
- screws connecting ties or other components to studs have increased contact area and are less susceptible to overturning or loosening;
- the thicker material is less affected by corrosion;
- the studs are less susceptible to damage before installation;
- web crippling for both brick ties and the stud to track connection is less critical; and
- brick ties connected to the flange will be less flexible.

Industry information indicates that the price increase to cover the cost of changing from 20-to 18-gauge steel is relatively small. Therefore, it was decided that the greatly improved strength and stiffness characteristics, durability properties, and buildability aspects associated with use of 18-gauge studs were very cost-effective.

## *7.4 BASIS FOR DESIGN OF THE UPPER AND LOWER TRACKS*

Standard practice is to use upper and lower tracks to act as the reaction points for the steel studs. These tracks may also serve to:

- provide bracing against torsional buckling;
- facilitate stud alignment during installation;
- provide a continuous edge for caulking or otherwise sealing the wall against air flows;
- provide a platform for support of drywall or other wall sheathing; and
- provide a movement joint (normally at the top track).

The tracks are normally anchored to the structure as described in Section 7.6. Tests have indicated that using the same gauge for tracks as than that used for studs is adequate to develop web crippling of the studs. However, the practice of using a thicker gauge of steel for the tracks than that used for the studs (i.e., 16-gauge tracks combined with 18-gauge studs) has the advantage of stiffening the connection and reducing susceptibility to damage.

In addition to assuring adequate strength, the stiffness of the design detail needs to be checked where lateral displacement might affect the performance of the veneer and where internal finishes might be damaged by local deformations. In lieu of a comprehensive analysis, it is recommended that under full service load, the local horizontal displacement at the track connection not exceed 1.2 mm. (A comprehensive analysis is recommended when cracking of the veneer or size of crack is particularly critical.)

## DESIGN OF THE LOWER TRACK CONNECTION

Stud-to-track connections are typically screwed or welded so that the flanges are mechanically connected. This detail provides torsional restraint but does not transfer shear from web to web. Therefore the stud reaction force is transferred in bearing of the stud flange against the upstanding leg of the track. The track must be checked for local bending in the upstanding leg and, as mentioned for stud design, web crippling at the end of the stud should be checked. Also, as illustrated in Figure 7.5, cut-outs near the end of the studs must not be permitted.

Before cracking of the veneer, the horizontal reaction at the bottom track may be relatively small because the veneer is typically supported by friction with the shelf angle at its base. However, as shown in Figure 7.3, following cracking of the veneer or if ties are very flexible, the bottom track may be required to resist approximately half of the lateral load on the wall.

While the stud should be firmly pushed into the track to minimize the gap between the end of the stud and the web of the track, allowance for up to 6-mm gaps should be included in the design. Specifications should call for an erection tolerance of 4 mm as recommended by CSSBI.[23]

Welding of the stud to the track, as shown in Figure 7.2, provides a superior connection for both strength and stiffness. Alternative details, including web connections, have also been used effectively.[24] Figure 7.7 illustrates a Tee connection which provides a very strong and stiff connection and has the added advantage of allowing some adjustability for stud lengths. However, connections of this type can be a problem where reinforcing steel in the slab or beam may interfere with fastener locations.

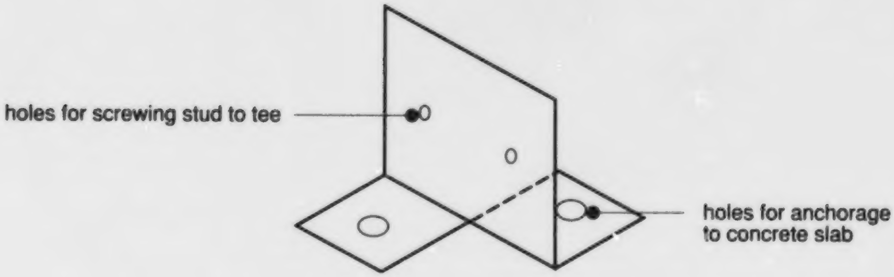
## DESIGN OF THE UPPER TRACK CONNECTION

In the usual steel stud applications, the stud system is intended to be non-axial load-bearing and should only resist loads normal to the wall (e.g., wind pressure). To ensure non-axial load-bearing behaviour, it is necessary that combinations of deflections and shortening of the load-bearing structure do not result in transfer of loads into the steel stud system.

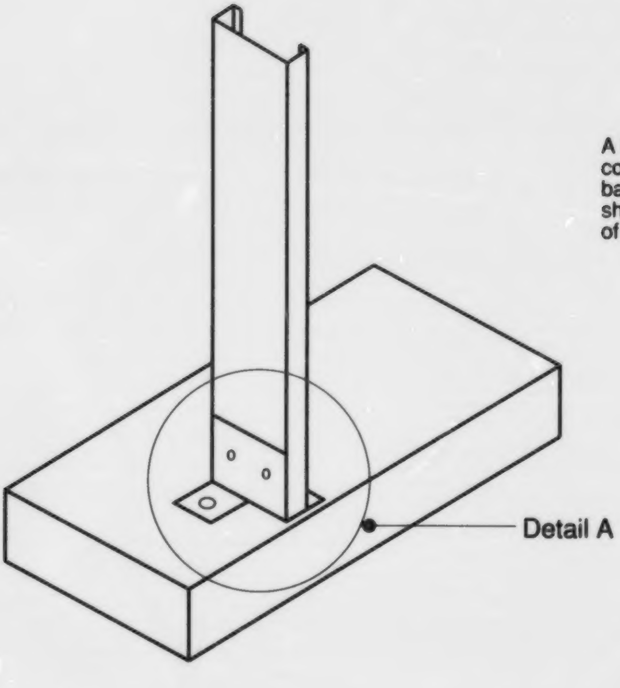
Therefore, as discussed in Chapter 4, the size of movement joint required depends typically on the shortening of the structure per storey and on the long-term deflection of the beam or floor system. Although each building needs to be assessed individually, for normal storey heights and spans encountered in reinforced concrete construction, a 12- to 15-mm movement joint has been standard practice. For relatively flexible floor systems where long-term deflections may be in the order of span/360, larger movements must be accommodated. In addition, a factor frequently not considered is the thermal expansion of the steel stud system due to fire. Taking this factor as well as construction tolerances into account, the size of a movement joint could exceed 25 mm.

Obviously the provision of any movement joint has implications on the stiffness of the backup wall, and the requirement of a relatively large joint, such as 25 mm, would place added emphasis on this aspect of design. Care is also required in the detailing of movement joints to ensure that disengagement does not occur because the lower floor deflects relative to the upper floor. Therefore use of track with 60-mm legs at movement joints may be required.

From the previous discussion, it is clear that screwing studs to the track at locations of the movement joint is unacceptable. A number of movement joint details have been developed in practice to support the steel stud while permitting movement.


holes for screwing stud to tee
holes for anchorage to concrete slab

Detail A - Tee connection



A light-gauge track or some other component may be needed at the base of the wall to support sheathing and provide continuity of air and vapour barriers.

Figure 7.7 Use of tee connection to attach studs to floor slabs

Some are illustrated in Figure 7.8 and will be commented on here:

**Free Floating Stud.** As shown in Figure 7.8(a), this detail, one of the simplest in use, relies on the track only to provide out-of-plane support. Therefore bridging or internal bracing is required near the tops of the studs to provide torsional stiffening and in-plane restraint.[25]

**Nested Tracks.** This detail permits the studs to be screwed to an inner track for support. Then, as shown in Figure 7.8(b), by nesting this track inside another track with shorter legs, vertical movement is permitted. Because the studs have a more effective bearing area along the outside track, this detail generally is thought to provide greater stiffness than (a).

**Web Connection.** A web connection of the type shown in Figure 7.8(c) is sufficiently flexible in the vertical direction to allow free vertical movement while providing both in-plane and out-of-plane horizontal restraint. The advantage of improved out-of-plane stiffening can be coupled with a reduced requirement for leg height and gauge of track. Figure 7.8(d) shows a similar detail but with sliding vertical movement accommodated by slots in the web connector.

**Boxed Track with Free Floating Stud.** This detail provides both in-plane and out-of-plane horizontal restraint for the end of the stud which is *free floating*. Thus, as is shown in Figure 7.8(e), it is able to accommodate the vertical movement. The boxes created by the nested, face-to-face tracks provide a relatively stiff support. The boxes should be filled with insulation to improve thermal resistance but, as is the case with the nested tracks, significant thermal bridging can occur with use of this detail.

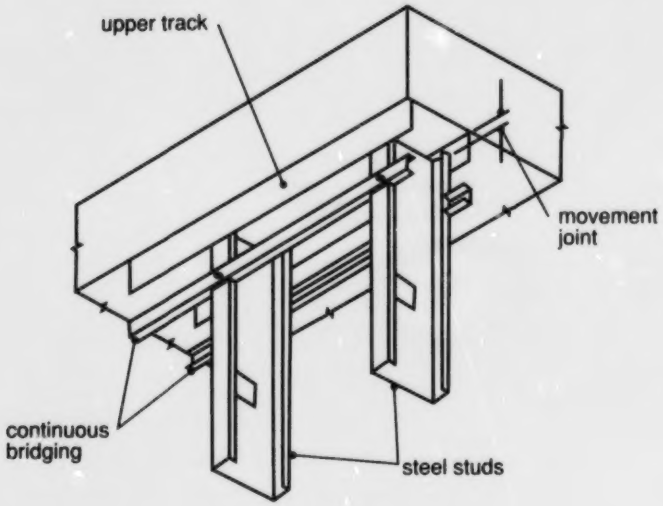
## *CONSTRUCTION*

As is illustrated in Figure 7.9 the most common error in construction of movement joints is that movement is inadvertently prevented by some feature of the construction, often resulting from incomplete design detailing. While screwing the stud to the track is the most obvious violation of free movement, attachment of drywall to the track and to the stud is effectively the same thing. Similarly, running the drywall the full height of the wall will also offer resistance to movement and mean that something has to give for movement to occur. In many designs the above features have not been sufficiently thought through.

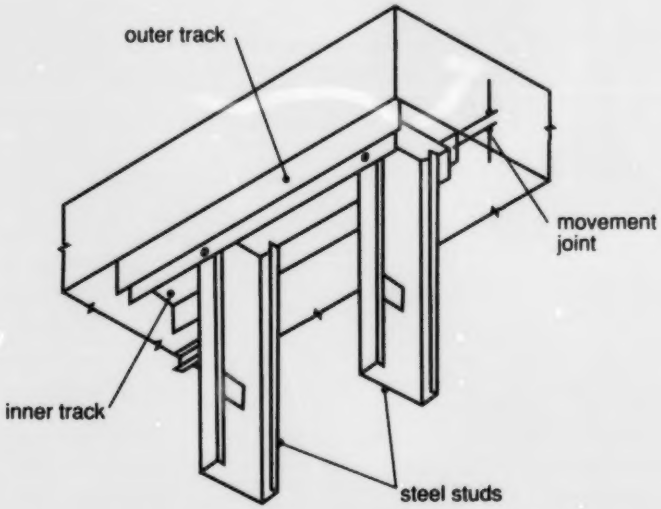
Where a gap at the top of the wall covering is not aesthetically acceptable, provision of the movement joint at the bottom of the wall so that the joint and the movement can be concealed behind baseboards or other trim may be a practical solution. While this entails *hanging* the wall from the upper track, this has the structural advantage of reducing the displacements of the top tracks significantly by providing a stiffer connection. The more flexible connection associated with the movement joint will result in less displacement when placed at the bottom of the wall because of generally lower reaction forces at this location. (It should be noted that application of this concept requires that windows, air conditioners, etc. be supported from the top of the SS backup wall.)

Where tracks are discontinuous over the length of a panel, mechanical anchorage of the abutting ends of the tracks to the floor must be provided near both ends of the tracks as shown in Figure 7.10.

Tracks may be conveniently used as part of the structural framing above and below openings. Aside from assuring adequate flexural capacity, provision of a sufficiently strong and rigid connection to the adjacent studs is necessary.

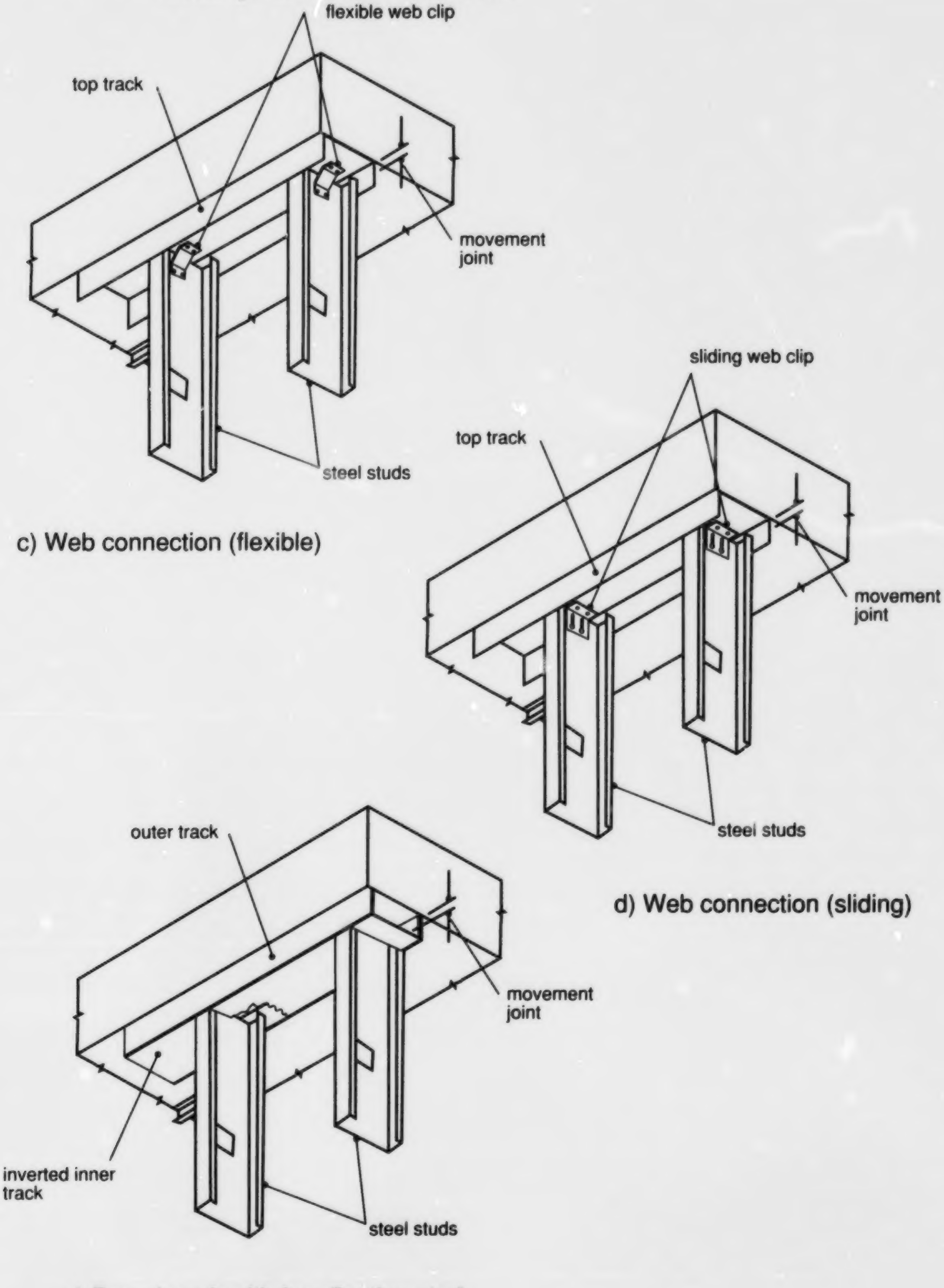

upper track
movement joint
continuous bridging
steel studs

a) Free floating stud


outer track
movement joint
inner track
steel studs

b) Nested tracks

**Figure 7.8** Typical movement joint details for upper track connection


flexible web clip
top track
movement joint
steel studs
sliding web clip
top track
movement joint
steel studs
outer track
movement joint
inverted inner track
steel studs

c) Web connection (flexible)

d) Web connection (sliding)

e) Boxed track with free floating stud

Figure 7.8 (continued) Typical movement joint details for upper track connection

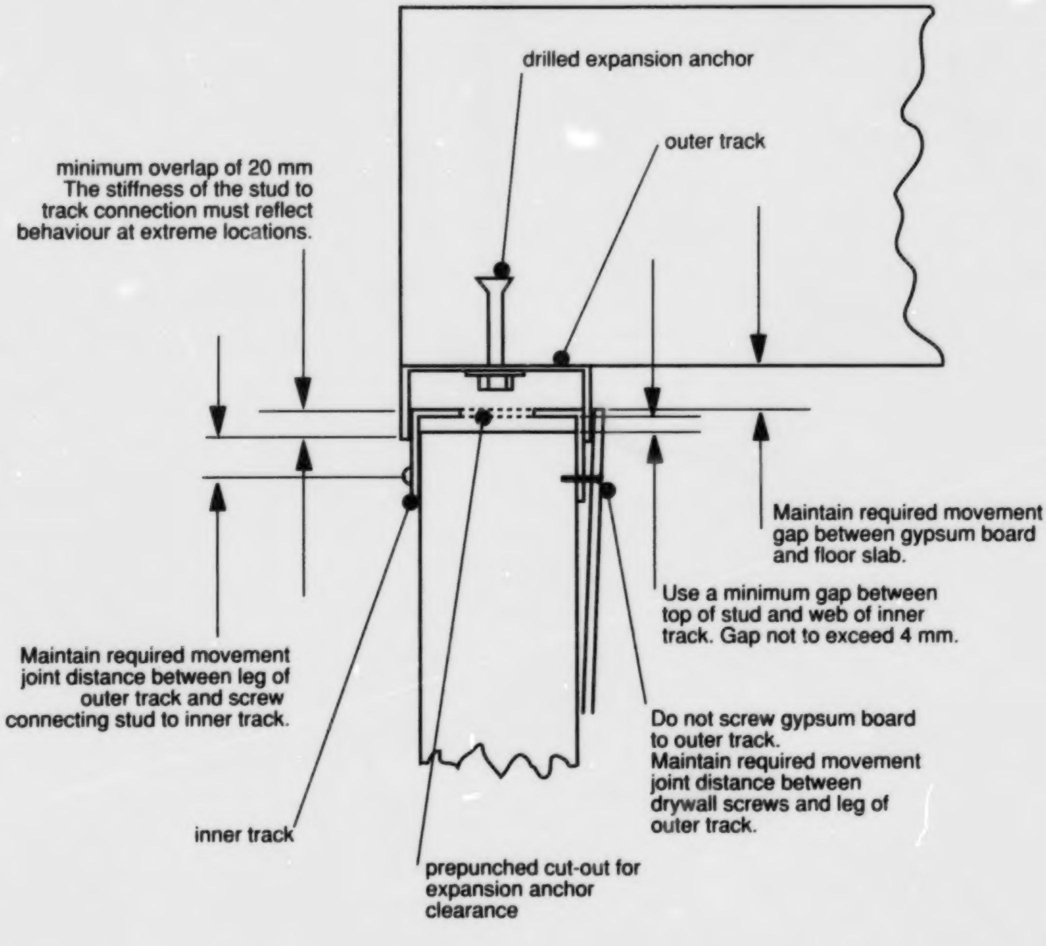

drilled expansion anchor
outer track
minimum overlap of 20 mm
The stiffness of the stud to
track connection must reflect
behaviour at extreme locations.
Maintain required movement
gap between gypsum board
and floor slab.
Use a minimum gap between
top of stud and web of inner
track. Gap not to exceed 4 mm.
Maintain required movement
joint distance between leg of
outer track and screw
connecting stud to inner track.
Do not screw gypsum board
to outer track.
Maintain required movement
joint distance between
drywall screws and leg of
outer track.
inner track
prepunched cut-out for
expansion anchor
clearance

Figure 7.9 Illustration of requirements to maintain movement capabilities of movement joints

Although various types of clip angles or other devices may be effective, an efficient and effective connection can be achieved by cutting the end of the track and bending the web as shown in Figure 7.11. This type of connection will resist torsion on the stud rather than cause it.

Maintaining a proper movement joint requires that construction tolerances be accounted for. While small variations in storey height can be accommodated in the size of the movement joint, larger deviations must be corrected by using different lengths of stud.

## *CONCLUDING REMARKS*

The provision of an adequate movement joint is an essential component of a steel stud system design, since otherwise the system may become load-bearing at some time in the service life of the structure. The type of track connection must be chosen with care and with full consideration of potential interaction with other construction features. Construction must ensure that movement as intended in the design is, in fact, provided.

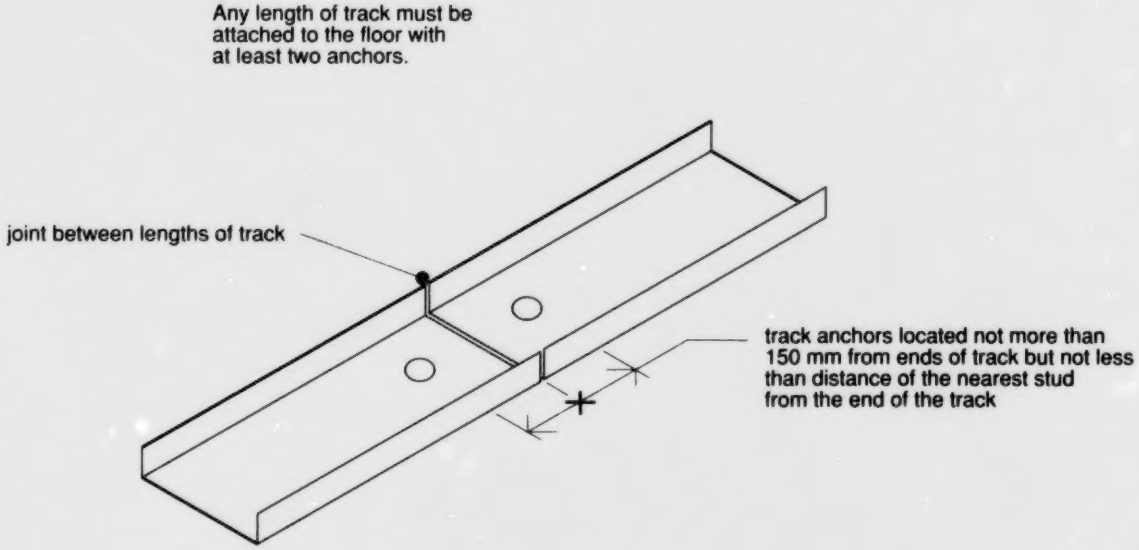

Any length of track must be attached to the floor with at least two anchors.
joint between lengths of track
track anchors located not more than 150 mm from ends of track but not less than distance of the nearest stud from the end of the track

Figure 7.10 Track splice

## *7.5 BRIDGING AND BRACING*

Some designs of steel stud systems have relied upon the wall sheathing to provide the in-plane stability and torsional bracing for the studs. While tests have shown such sheathings as gypsum board to be reasonably effective for the first application of load, repeated loading results in widening of the screw hole. Also, the presence of moisture substantially reduces both the stiffness of the gypsum board and the bearing capability around the screws.

Therefore, as was the case for overall flexural stiffness and strength, it is recommended that exterior gypsum board sheathing not be relied upon to contribute to the structural performance of the stud wall system.[26,27,28] While gypsum board on only one side is not very effective for preventing twisting of the studs, coupling it with moisture-proof exterior sheathing and attachment systems may be effective. (See final paragraph in this section.)

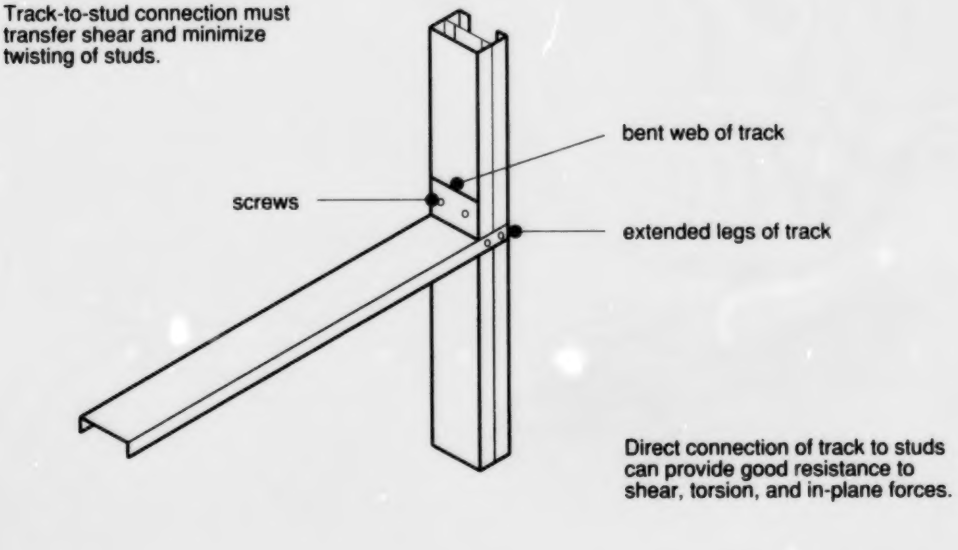

Track-to-stud connection must transfer shear and minimize twisting of studs.
bent web of track
screws
extended legs of track
Direct connection of track to studs can provide good resistance to shear, torsion, and in-plane forces.

Figure 7.11 Connection of track to studs for window framing

The most common form of bridging is internal through-the-stud bridging where a channel type of member fits snugly into prepunched, regularly spaced holes. The bridging member is placed vertically, then twisted sideways to fit snugly against the sides of the hole. This snug fitting may be one reason that positive connection of the bridging to the steel has been erroneously omitted on some jobs. However, when such a workmanship deficiency occurs, the bridging provides very little benefit. The normal method of positive connection of the bridging to the stud is to use a clip angle, as shown in Figure 7.12, and connect to the stud and bridging either by welding or by using a minimum of two widely spaced screw connections on each piece as shown. The bridging should be continuous and, where joined, should be jointed by welding or with a minimum of two screws on each side of a splice as shown in Figure 7.13.

Clause 8.3.2 of CAN3-S136-M84 (Cold Formed Steel Structural Members)[29] specifies a maximum spacing for discrete bracing of one-quarter of the span length. "Fewer braces may be used if it can be shown to be acceptable by rational analysis or testing."

For residential storey heights of 3.0 m or less, it has become common practice to use only one line of bridging at about mid-height of the wall, where the studs are restrained from twisting at both the top and bottom. However, tests show that internal bridging at this spacing does not provide sufficient torsional bracing to develop the full flexural capacity of the studs.

Bridging is required to resist the accumulated torsion between bridging lines. This torsional restraint is most effectively applied to both flanges of the studs. Therefore, the method of connecting the internal bridging member to the stud can have a significant influence on its effectiveness. Other than experimentally verified performances, there is little guidance available regarding the design of internal bridging connection details. Use of thicker-gauge clip angles and more efficient screw placement (screws near the bend in clip angles and near the flanges of the stud as shown in Figure 7.14) or welding have been shown to result in significant improvement. However design information is required to establish the actual flexural capacity limits associated with specific sizes, spacing, and connection details for internal bridging. Here, it should be pointed out that where deflection or end bearing control the design of the steel studs, bridging to develop the full flexural strength of the steel studs may not be required.

An alternative to internal bridging is to use surface bracing of tension straps or channels where the channel legs of the braces have been cut out at the locations of the studs and are screwed to the studs as shown in Figure 7.15. Tests on the channel braces[30] have shown that this system works well but has the disadvantage of not easily accommodating uneven spacing of studs, although new cut-outs can be made and existing cut-outs strengthened, if there are not too many of these odd measurements. Surface bracing channels are required on both sides of the stud. Alternatively, tension straps may be used. In either case the anchorage of surface bridging is particularly important.

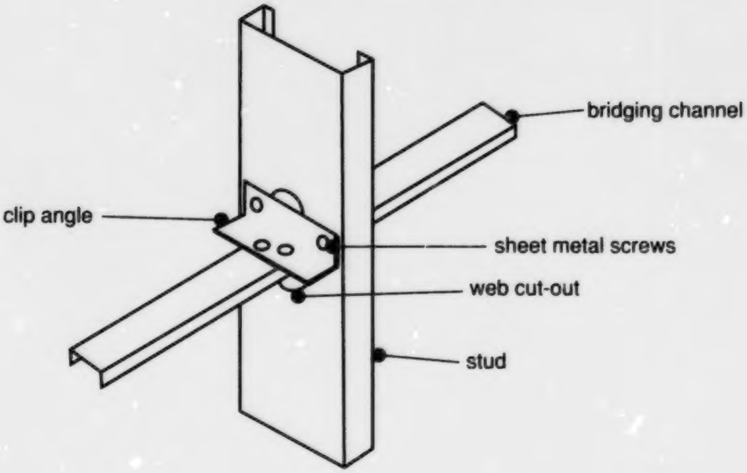

bridging channel
clip angle
sheet metal screws
web cut-out
stud

Figure 7.12 Screwed connection using clip angle to connect internal bridging to stud

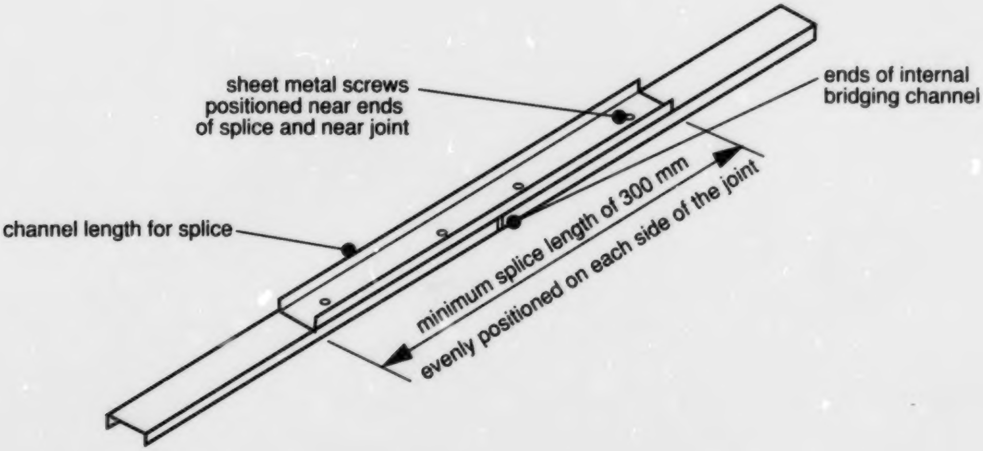
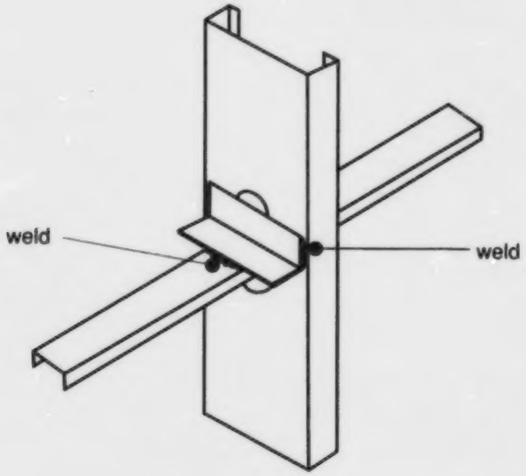
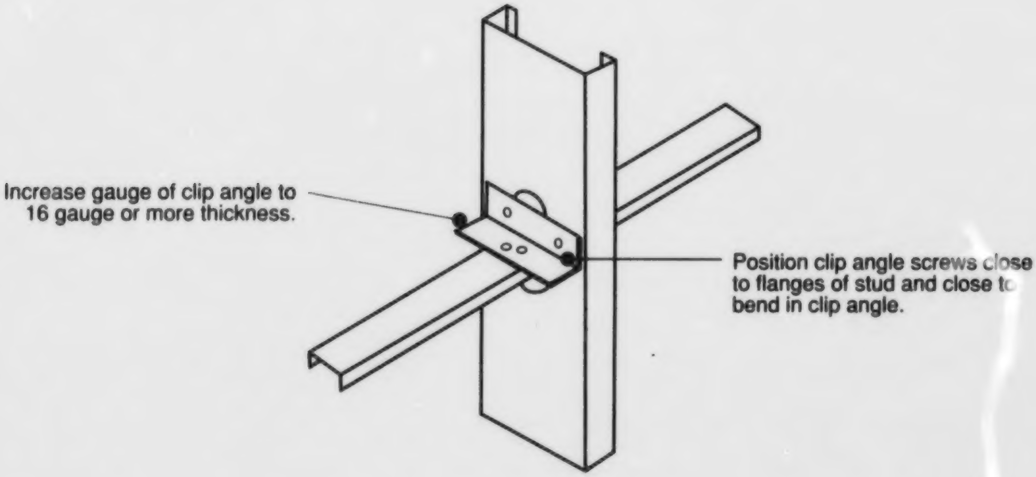

sheet metal screws positioned near ends of splice and near joint
ends of internal bridging channel
channel length for splice
minimum splice length of 300 mm
evenly positioned on each side of the joint

Figure 7.13 Screwed splice connection for internal bridging



a) Welded connection


Increase gauge of clip angle to
16 gauge or more thickness.
Position clip angle screws close
to flanges of stud and close to
bend in clip angle.

b) Screwed connection

Figure 7.14 Improved details for connecting internal bridging to studs

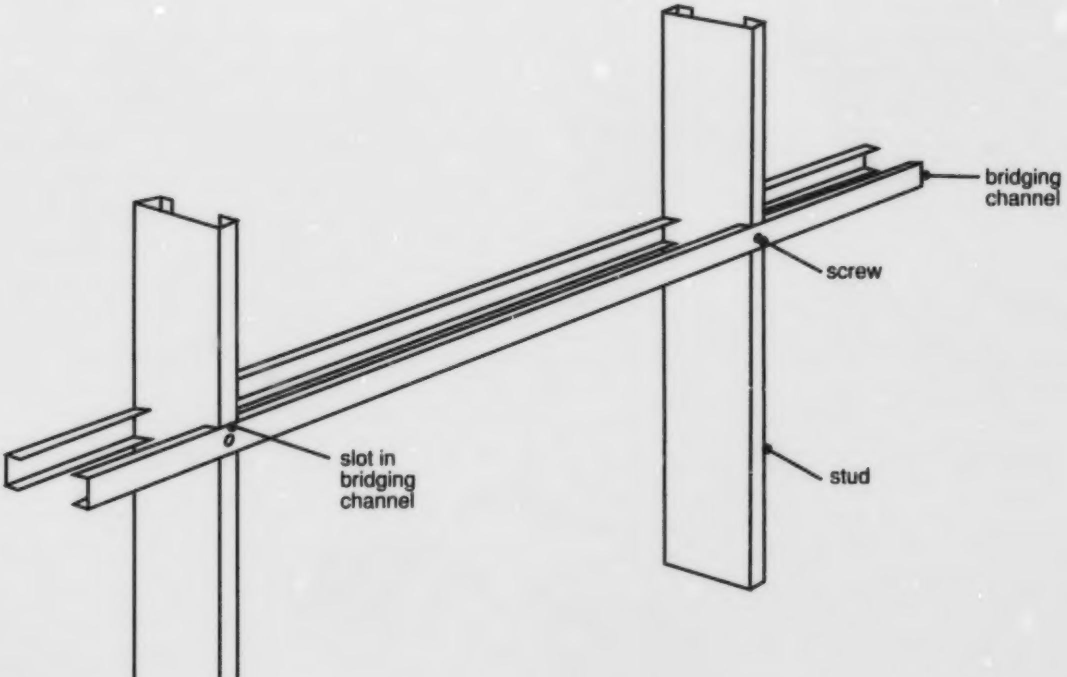

bridging channel
screw
slot in bridging channel
stud

Figure 7.15 Screwed connection for external bridging

As is the case for internal bridging, full flexural capacity is not achieved with a single line of bridging for stud lengths of normal storey height. Similar comments apply.

The spacing of bridging shall be as required to develop the required flexural strength of the studs, with additional bridging possibly being required near the movement joint, if the studs are designed to have a *floating end* in the upper track.

For inside sheathing, which should be less susceptible to wetting, it may be possible to provide attachments which will ensure that this layer will remain effective as lateral support for the studs. Further testing of current screw attachment or development of mechanical anchors which do not depend on bearing between screws and gypsum board may satisfy this requirement. If so, the requirements for interior-side steel bracing may be relaxed as research information becomes available.

## *7.6 ANCHORAGE TO THE FRAME*

Where the load on the stud is transferred to the track and from the track to the supporting floor system, the best connections for the track are drilled insert expansion anchor or cast-in-place anchors as shown in Figure 7.16. For these, the hole in the track should be equal to the diameter of the anchor and a washer should be used to help transfer force as the bolt is tightened. Various forms of concrete nails, screws, and shot-in connectors are available and have been used on many jobs.

However, caution is advised in their use. These anchors must resist a peeling action as well as direct shear and should be evaluated for these forces, including repeated loading. Also, the long-term ability of these to hold when quite small lengths of embedment occur should be evaluated independent of the capacity requirements. Spacing of the anchors affects the deflection of the track and therefore should not exceed 800 mm, unless design calculations indicate otherwise.

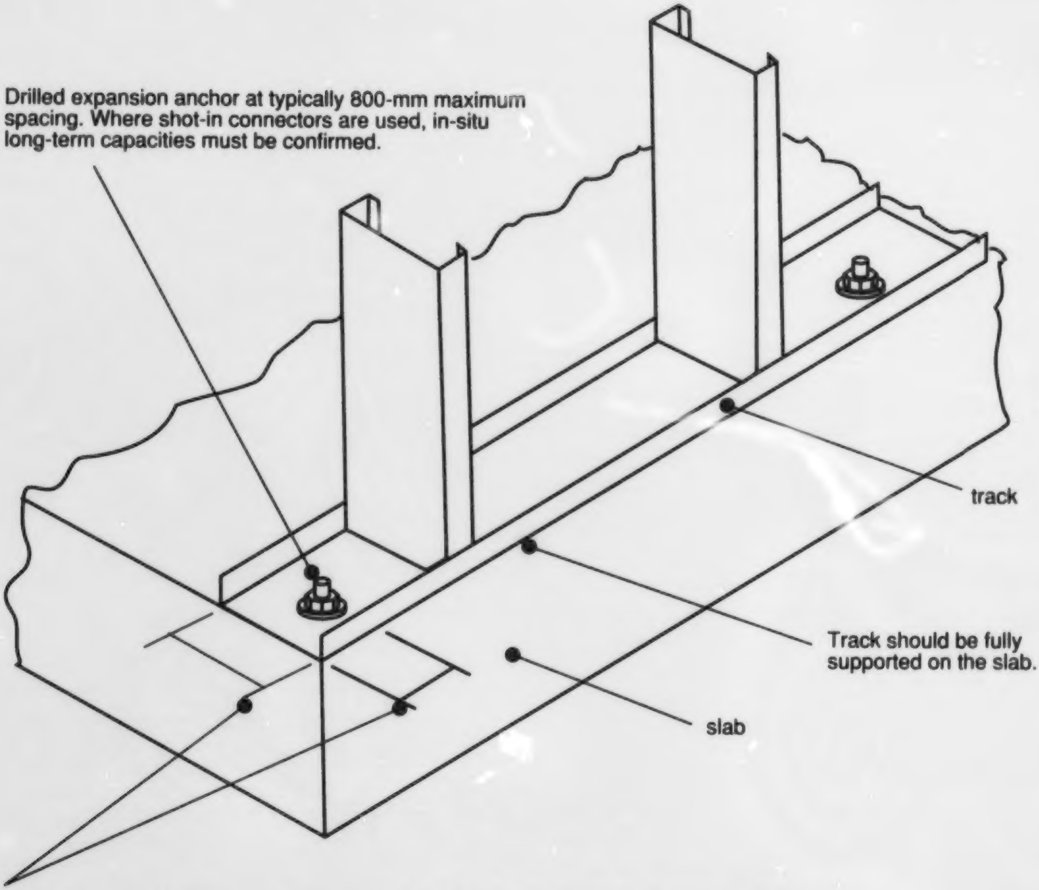
The same advice is applicable for studs connected to the floor system using a web-connected device (i.e., as shown in Figure 7.8(c) and (d)). The attachment of these devices through the track and to the floor does not rely on the track and separate attachment of the track is usually not necessary. Web connections can be used at either, or both, the top and bottom of a stud.

Adjustments in the location of the tracks can be used to correct minor variations in vertical alignment of floors. However, as is indicated in Figure 7.16, the track should not be positioned beyond the edge of the floor, unless tests or analyses show that lack of full contact over the web of the track will not adversely affect the performance of the BV/SS wall system. Similarly, minimum edge distances for the mechanical anchors must be maintained.

Anchorage to the side frame has not been common practice but, particularly if the veneer is tied to vertical parts of the supporting structure (i.e., wide columns or shear walls), the last stud should be fastened to the structure. Support of the veneer along the sides of the panel will result in two-way bending which can result in an increase in the cracking load for the veneer.[31] Elimination of movement between the stud and vertical part of the structure may also reduce the stress on materials required to maintain the air barrier between the last stud and the frame. Anchoring the end studs also provides racking stiffness and strength for the steel stud backup wall.

## *7.7 BRICK VENEER*

The structural design of the brick veneer has been discussed in general in Chapter 5, and those aspects that relate to building science issues are reviewed in Chapters 8 and 10. For brick veneer as part of the BV/SS system, the structural behaviour does have important effects on both structural and building science aspects of performance.



Drilled expansion anchor at typically 800-mm maximum spacing. Where shot-in connectors are used, in-situ long-term capacities must be confirmed.

Track should be fully supported on the slab.

Edge distances for expansion anchors shall conform to manufacturer's specifications.

Holes in track shall provide minimum clearance for anchor bolts. Washers must be used and nuts torqued to prevent slipping of track.

Figure 7.16 Anchor connection between track and slab

For large spans for steel studs, calculations indicate that cracking of brick veneer may occur at relatively low horizontal forces. This means that substantially increased rain leakage is highly probable and, in turn, the potential for damage due to moisture is greater. An alternative design approach,[32] which has merit from a theoretical point of view at least, is the idea of initially creating a horizontal crack in the brick veneer, say, at mid-height. Because the location of the crack is known, the mortar joint can be raked back and caulked so that additional water penetration will not result from cracking. Provision of this initial crack will allow the backup wall to take a much larger share of the load and require a much higher load for formation of additional cracking. This higher load typically would be well above design load levels.

In addition, if the veneer is supported around all four sides, tests have shown that considerable increases in load are required for brick veneer to crack and form a failure mechanism.

### *7.8 TIES*

Many ties have been developed to attach veneer to the SS backup wall. In selecting a tie system the capacity and deformation behaviour of a tie itself as well as the full effects of the range of adjustability, including positioning over the stud, should be taken into account.

An experimental study[33] of a wide range of tie types and loading conditions revealed an equally wide range of performance characteristics. For the full range of adjustability, some existing ties do not have adequate strength or stiffness to satisfy the highly non-uniform tie load requirements associated with SS backup walls. Even though CAN3-A370-M84 does not specifically cover adjustable ties, the load factors for various loading conditions are applicable. Therefore, it is recommended that reliable information on the strength and stiffness of a tie system (including attachment to the stud) for the full range of adjustability be obtained in order to make a proper design-based selection. As was discussed in Section 5.6, limits on mechanical play and stiffness similar to those suggested in BIA Tech Note 28B[34] are recommended.

Particularly for Canadian climatic conditions, the implications of using a screw in tension to transfer the tie force to the steel studs must be considered. Critics of this system have coined the term *hanging by a thread* with some justification where:

- inadequate corrosion protection may lead to loss of pullout strength;
- overturning, drifting, or other incorrect installation of the screw may seriously lower the pullout strength;
- installation through drywall or insulation may allow loosening of the screw under repeated load applications and also a loss of compressive strength and stiffness of the drywall or insulation;
- dissimilarity in materials and the rough hole created by self-drilling screws may result in crevice corrosion around the hole in the stud; and
- lack of ability to inspect installation may result in screws not even engaging the studs.

The potential for corrosion will depend largely on the likelihood of repeated wetting of the screw with rain penetration or condensation of exfiltrating air — the likely sources of moisture. External insulation or other sheathing over the screws will reduce the potential for wetting. Alternatively, screws in shear, two-screw systems, bolt and nut systems, or those which transfer tension by other mechanisms may be more suitable types of ties.

In many cases the most conveniently located (and sometimes the only feasible location) ties are on the sheathing material fastened to the stud. Although some design guides recommend moisture protection of gypsum board, for instance, as a means of protecting this bearing area from deterioration, tests have shown that even without any deterioration of the material, the capacity and stiffness are dramatically reduced because of indentation of the drywall material.[35] Also, the effect of screws loosening due to cycled load should be considered.

Extra ties in the vicinity of openings are required because of the added load, which must be transferred between the BV and the SS wall in this region. CAN3-A371-M84[36] provides guidance on this subject.

## *7.9 KEY CONSTRUCTION REQUIREMENTS*

From the preceding discussion of BV/SS structural requirements and other considerations, the following key requirements for construction of the system stand out:

- Bent, twisted and otherwise damaged steel studs must not be used.
- Tracks should be properly anchored. Any projection of the track beyond the floor edge must be approved by the designer.
- Movement joints at a track must provide the specified gap, otherwise the studs may eventually buckle because of floor deflections and shortening of the frame.
- Where floor to ceiling heights vary because of field tolerances, it may be necessary to field-cut studs to maintain an adequate movement joint. Stud gaps within tracks also must not exceed specified values, otherwise the strength and stiffness of the wall assembly may be compromised.
- Stud perforations must be removed from stud ends by at least two times the stud width.
- Built-up studs at openings must be tied together to share the load.
- The proper installation of bridging, including splicing, is vital to prevent premature twisting failure of the stud assembly.
- Ties that induce web crippling must not be attached near perforations in the webs of studs.
- System performance depends on proper tying together of many components by means of screws or welds. Regarding screws, essential factors are use of the specified screw size, adequate tightening — yet not overturning or allowing the screw to drift — and ensuring screws engage the stud. Regarding welds, properly qualified welders, experienced in welding light-gauge steel, are required. Any welded area must be touched up to restore corrosion protection.
- No materials may be substituted without approval of the designer. Particularly, specified levels of corrosion protection must be supplied and cannot be infringed upon in any installation procedure.
- Engineering shop drawings and inspection should be provided by an engineer familiar with steel stud construction.

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# *PART 3 BUILDING SCIENCE CONSIDERATIONS*

## *CHAPTER 8*

## *GENERAL BUILDING SCIENCE REQUIREMENTS*

### *8.1 INTRODUCTION*

Aside from their structural functions, walls provide the environmental separation between internal and external conditions. While requirements related to fire protection, acoustic barriers, and general security are important, provision of thermal, moisture, and air barriers to maintain the desired interior environment is the main focus of this chapter. The combined effects of the Canadian climate,[1] modern environmental conditions, such as humidification, and changing construction methods and materials require some special attention to design concepts and construction details. For satisfactory long-term performance, it is necessary to assure proper functioning of the wall components both individually and as they interact with other components. Otherwise, durability and the general ability of the construction to function over the long term may be compromised as may the structural and aesthetic requirements.

Although the basic functions of components of BV wall systems were described in Chapter 2, general building science design requirements and construction considerations common to BV wall systems will be discussed in the following sections.

### *8.2 VENEER*

Walls are primarily intended to keep out water (rain and snow) and wind (hot or cold air) as well as to serve as a thermal barrier. The extent to which the veneer can be relied upon to perform these functions is highly variable, and in general veneer is not considered to be the ultimate air or moisture barrier, nor does it contribute significantly to the thermal resistance of insulated walls. In the extreme, veneer can be looked on as a decorative facing capable of acting as a rain screen and as a wind and sun screen.

The wall system should be designed based on an evaluation where waterproofing is considered to be a two-stage barrier with the veneer as the first stage and the cavity-backup wall components as the second stage. Despite this philosophy, the veneer should be detailed and constructed to provide water and wind resistance so that the effectiveness of the second stage is not continuously tested. If water is allowed to penetrate readily through the veneer, the cavity-backup wall components are really a single-stage system which means failure is assured if some fault exists in the system.

Although rain may quickly wet exposed areas of the face of a masonry wall, only during the most prolonged or frequent rainfalls are the units and mortar likely to be completely saturated. If water passes through, it is generally through fine capillary passages (actually unbonded areas) at the unit to mortar interface, through unfilled mortar joints or through movement joints, or cracks. Hence it is important that:

- mortar completely fills head and bed joints;
- mortar and bricks are compatible to form a good bond to resist cracking;
- concave or V-shaped tooling of the exterior face of the mortar joints be done to compact the mortar against the units and help close capillary cracks; and
- flush, raked or extruded mortar joints which catch water running down the wall and are not compacted, are avoided for rain exposed conditions.

The different types of joints are illustrated in Figure 8.1.

Raindrops that actually hit on a crack are not the main cause of leakage. Rather water running down the wall face is drawn into the capillary passages at the joints and, if there is pressure due to wind, the water will flow through the wall. Water bridging larger cracks or holes may also be carried into or through the wall by wind pressure and gravity.

Although leak-proof, solid masonry walls are attainable, the use of a wide variety of materials and the kilometres of mortar joints in any building make it difficult to ensure satisfactory performance.[2,3] Therefore, the open rain screen principle is used where water that penetrates the thickness of a veneer is allowed to run down the inside face of the veneer and then directed back to the outside face of the wall through weep holes located at flashing on shelf angles.[4]

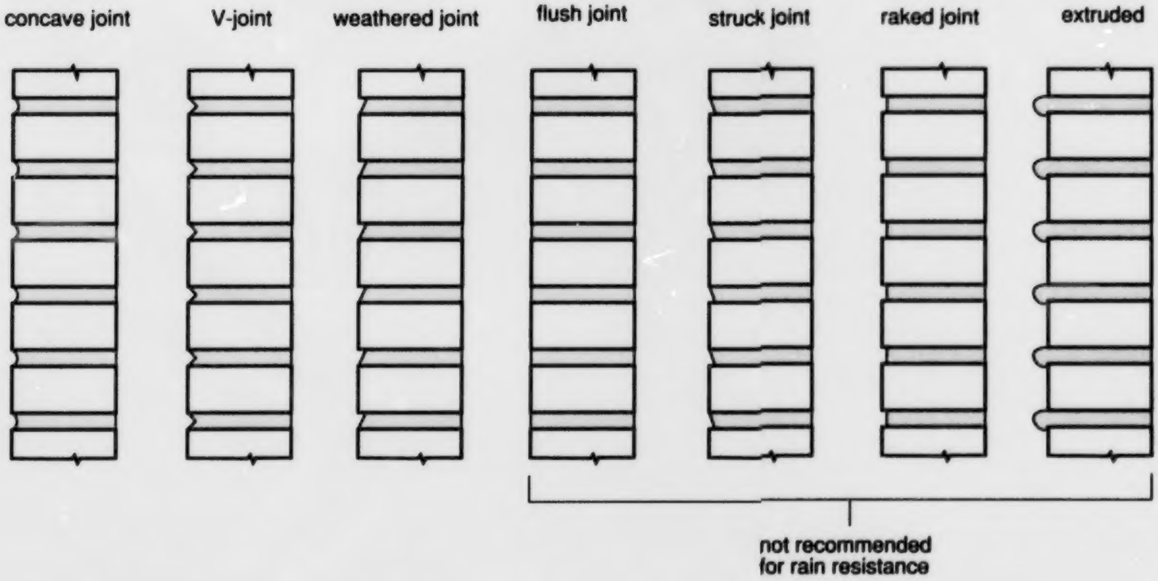

concave joint
V-joint
weathered joint
flush joint
struck joint
raked joint
extruded
not recommended for rain resistance

Figure 8.1 Illustration of different types of mortar joints

For rainscreens to work best, it is not advisable that the brick veneer be supported on the floor with the backup.[5] One reason is that water in the cavity can have direct access through the joint at the base of the backup wall into the interior. Also, water can flow under the flashing directly into the building and the exposed floor slab provides an extensive cold thermal bridge. An alternative, which avoids the problem of a direct leakage path but does not address the thermal bridge problem, is to place a recess at the edge of the slab to lower the base of the veneer below the base of the CM backup.

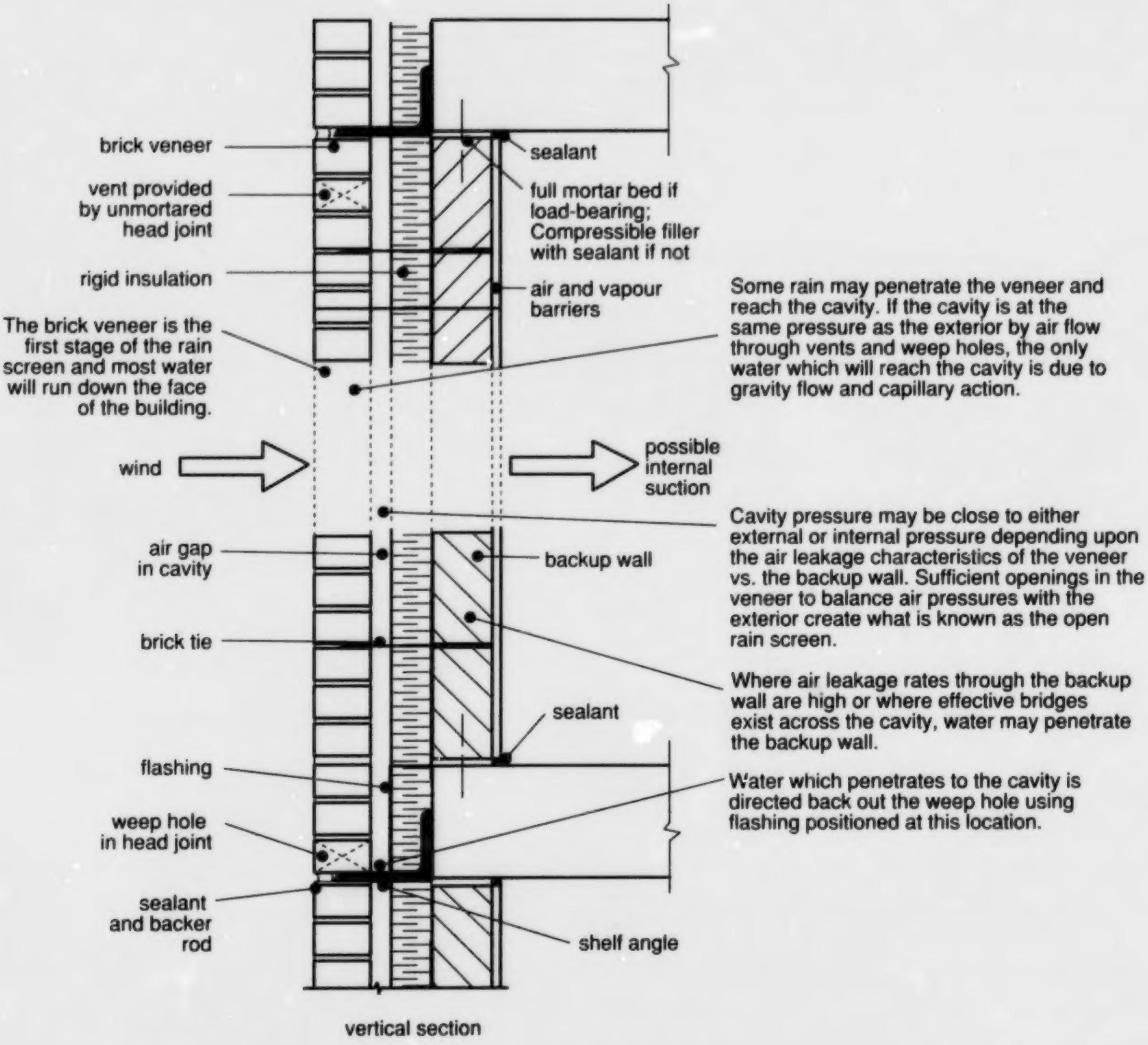
Figure 8.2 contains illustrations and comments about the functions of the BV wall system components acting as a two-stage rain barrier according to the rain screen principle. Design of the veneer as either a rain screen or an open rain screen may not make much difference in its actual operation but can influence design of the wall components. In conjunction with the cavity between the veneer and the backup wall, the veneer must be designed to allow moisture which gains access to the cavity, either through rain penetration or through condensation, to be removed.[6] Water which runs down to the bottom of the cavity can be drained out of weep holes at the bottom of the wall. In order that wetness in the cavity can be dried out, vents near the top of the wall help to allow air to circulate through the cavity. Therefore, small intentional holes that allow air and, to a limited extent, water to flow through the veneer will exist. The presence of these holes offers the possibility of pressurizing the cavity. In fact, the open rain screen concept relies on the use of intentional openings in the veneer (vents and weep holes) to create pressure equalization in the cavity so that external air pressure (wind) will not tend to force rain through the veneer.

For the second stage to work most effectively, both pressurization of the cavity and provision of an airtight backing are extremely important. The extent to which the cavity can be pressurized will not only limit the amount of water which is carried through by wind, but also decrease the tendency for water, which penetrates the veneer by capillary action or gravity, to be carried across the cavity.

As discussed for wind loading in Section 3.3, there are many reasons why full pressure equalization of the cavity with the exterior may not be achieved.[7,8] As depicted in Figure 8.3 (a), rain water may actually be carried in by air passing through weep holes and vents. Movement of air in the cavity can carry the water across to the backup wall and distribute it along the wall area; air leakage through the backup wall can then draw moisture into and through it. Therefore, unless a high level of pressure equalization can be achieved, it is recommended that the size of weep holes and vents be the minimum necessary for removing water from the cavity area.

To the extent possible, compartmentalization of cavities should be used to reduce the potential for air pressure differences on the surface of the building, thereby causing horizontal air flow through cavities. In addition to blocking corners as shown in Figure 8.3(b), vents and weep holes generally should be positioned away from corners where significant by large air pressure differences can lead to large air movements through the cavity.

Laboratory tests[9,10] have shown that high air leakage through the backup walls can cause water to *jet across* the cavity and even climb up the backup wall to extend the area of wetting. Although the backup wall should not allow air leakage, this possibility also supports the suggestion that vents not be over-sized and perhaps admit extra rain water.


brick veneer
vent provided by unmortared head joint
rigid insulation
sealant
full mortar bed if load-bearing; Compressible filler with sealant if not
air and vapour barriers
wind
possible internal suction
air gap in cavity
backup wall
brick tie
sealant
flashing
weep hole in head joint
sealant and backer rod
shelf angle
vertical section

The brick veneer is the first stage of the rain screen and most water will run down the face of the building.

Some rain may penetrate the veneer and reach the cavity. If the cavity is at the same pressure as the exterior by air flow through vents and weep holes, the only water which will reach the cavity is due to gravity flow and capillary action.

Cavity pressure may be close to either external or internal pressure depending upon the air leakage characteristics of the veneer vs. the backup wall. Sufficient openings in the veneer to balance air pressures with the exterior create what is known as the open rain screen.

Where air leakage rates through the backup wall are high or where effective bridges exist across the cavity, water may penetrate the backup wall.

Water which penetrates to the cavity is directed back out the weep hole using flashing positioned at this location.

Figure 8.2 Use of brick veneer as a rain screen

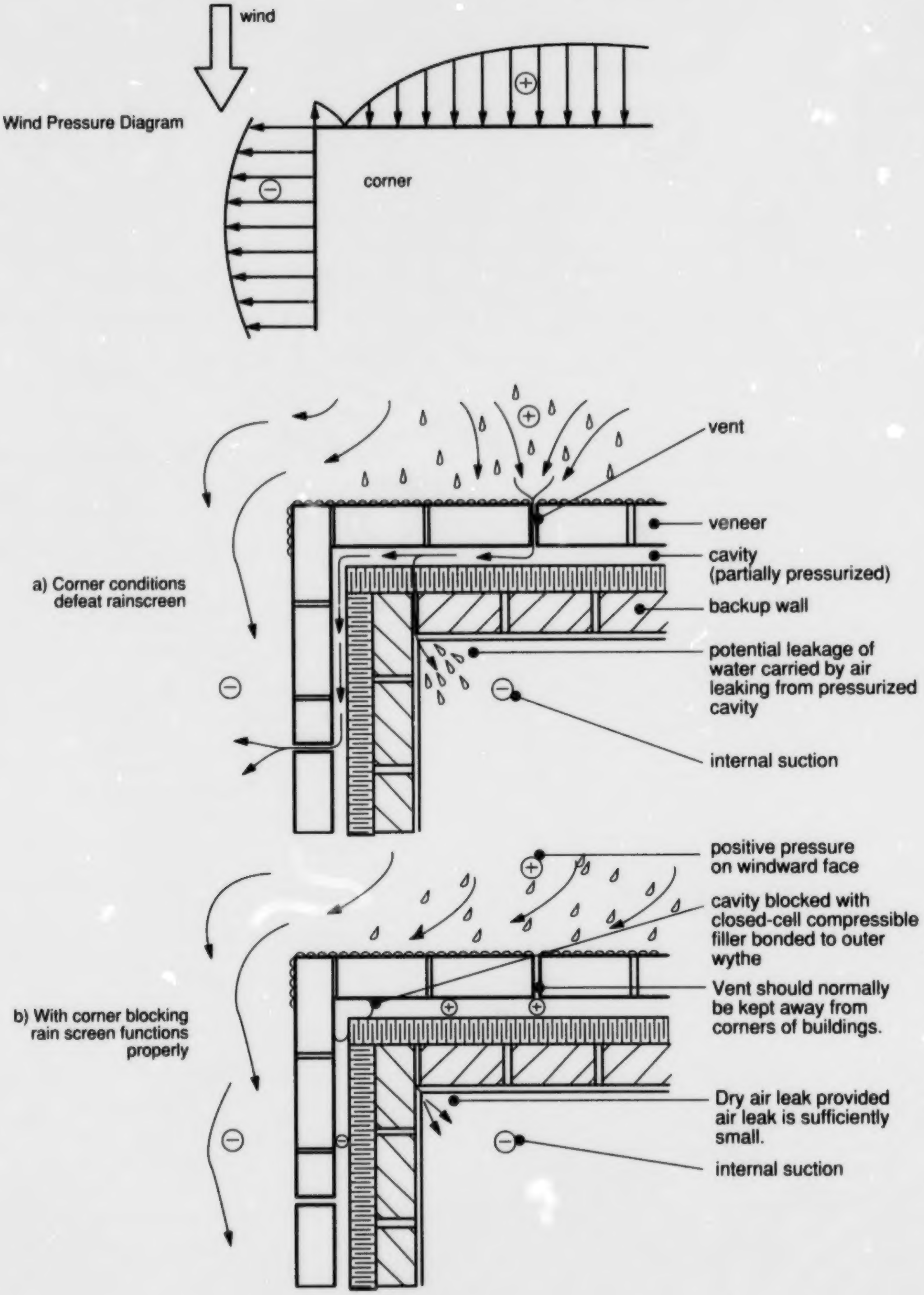

wind
Wind Pressure Diagram
+
−
corner
+
vent
veneer
cavity (partially pressurized)
a) Corner conditions defeat rainscreen
backup wall
potential leakage of water carried by air leaking from pressurized cavity
−
−
internal suction
positive pressure on windward face
+
cavity blocked with closed-cell compressible filler bonded to outer wythe
Vent should normally be kept away from corners of buildings.
b) With corner blocking rain screen functions properly
+
+
−
Dry air leak provided air leak is sufficiently small.
−
−
internal suction

**Figure 8.3 Illustration of pressure equalization problems at corners of buildings**

*Source: Guide to Energy Efficiency in Masonry and Concrete Buildings, Masonry Council of Canada.*

Typically, weep holes are provided in the bottom course of the veneer at 800 mm on centre, whereas location and spacing of vents has remained much more a designer's perogative. While no definitive information on the required amount of venting is available, it is common sense to avoid placing vents at locations near corners where air flow may carry large amounts of water into the cavity. Similarly, water drainage patterns over the wall should be evaluated to avoid placing vents at such high flow areas as edges of sills.

### *8.3 CAVITY*

The cavity between the veneer and the backup wall is intended to provide a means for water, which penetrates through the veneer, to be directed back out of the wall through flashing and weep holes at the bottom of the wall. Therefore, as discussed in Section 8.2, it is not necessary for the BV to be completely impermeable. However, several factors have cast doubt on the wisdom of accepting leaky BV walls as representing acceptable quality of materials and construction. This is thought to provide an excessive reliance on the open rain screen as the principal method of avoiding problems due to rain penetration. In terms of effectiveness of pressure equalization, the variations of wind pressure with time and location on the faces of buildings would require the cavity to be compartmentalized into fairly small areas. While this is possible, it introduces yet another wall component into the construction process which will have its own quality requirements and vulnerabilities.

Also, because these baffles or *compartment walls* cross the cavity, they provide a potentially large path for movement of moisture across the cavity to the backup wall. In addition, the degree to which wind gust pressures are balanced depends on the size of openings in the veneer compared to leakage rates through the backup wall as well as the volume of air in the cavity and the stiffness of backup wall.

While many building investigators have reported seeing or testing brick walls which *leaked like a sieve*, the fact is that many brick veneer walls show no readily visible signs of leakage. That is, there is no indication of wetting or resulting deterioration either inside or outside the building, nor is there any sign that water has ever drained out of the weep holes.

(Note: There are regional differences where for instance in the Atlantic Provinces, there is significant evidence of rain penetration of walls perhaps as a result of more frequent and longer duration of "horizontal rain" than in other parts of Canada. Also, there is evidence that slab-supported veneer wall systems are more susceptible to allowing moisture penetration of the backup wall.)

Even where construction is carefully supervised, some mortar droppings will partially fill the cavity at the bottom of the wall and hence the weep holes will tend to be plugged. In addition, as the brickwork progresses, mortar fins protruding from the back of the wall will tend to bridge across the cavity particularly where the air gap in the cavity is only 25 mm or less in width. These fins plus ties and mortar bridges on ties can all provide paths for water which penetrates the veneer to enter the backup wall rather than be directed back out of the cavity. Figure 8.4 illustrates these difficulties.

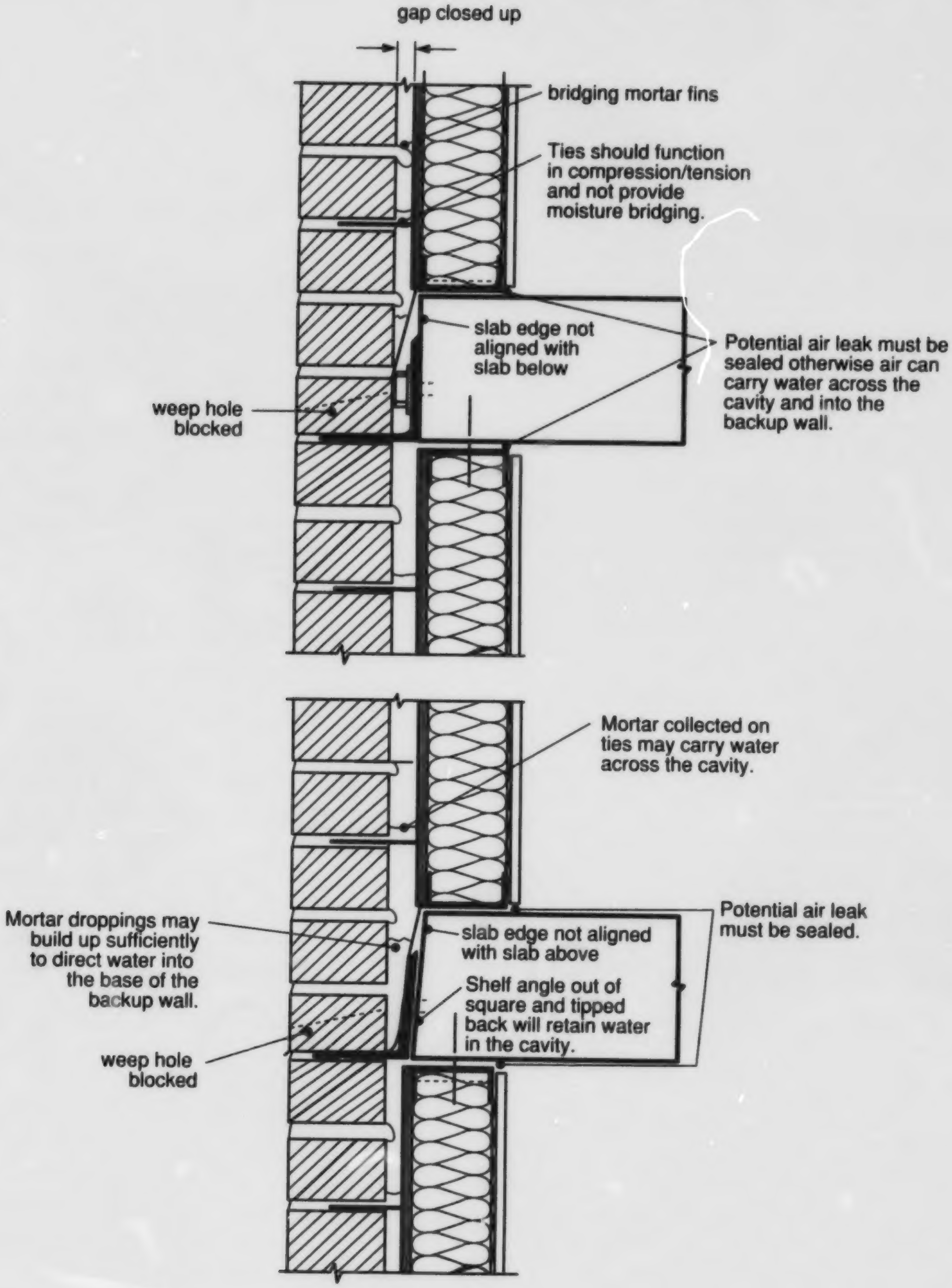

gap closed up
bridging mortar fins
Ties should function in compression/tension and not provide moisture bridging.
slab edge not aligned with slab below
Potential air leak must be sealed otherwise air can carry water across the cavity and into the backup wall.
weep hole blocked
Mortar collected on ties may carry water across the cavity.
Potential air leak must be sealed.
Mortar droppings may build up sufficiently to direct water into the base of the backup wall.
slab edge not aligned with slab above
Shelf angle out of square and tipped back will retain water in the cavity.
weep hole blocked

Figure 8.4 Mechanisms for transportation of water across the cavity

In the past, the choice of width of air gap in the cavity has been a design decision. However, the adoption — from low-rise home building specifications — of air gaps as small as 15 mm is not considered good practice for walls, exposed to wind and rain, of high-rise structures. Therefore, as shown in Figure 8.5, the recommended air gap in the cavity is 50 mm. This allows some small leeway for correction of line of the building and much improved drainage and air circulation (drying) in the cavity.

Although mortar fins are much less likely to bridge across to the backup wall, mortar droppings do tend to fill up the cavity on top of the flashing and plug weep holes. In addition to minimizing mortar droppings, other steps to allow proper drainage are to place a sash cord in the weep hole and remove it before the mortar droppings harden. This helps create a path for drainage. Alternatively, use of coarse gravel in the bottom of the cavity or placement of screening across the cavity at one or two courses above the shelf angle may help provide access for water which reaches the cavity to drain out. These and other construction approaches are illustrated in Figure 8.6. However, with excessive amounts of droppings, there is some danger that solid pieces of mortar may build up to a sufficient height to drain water toward the base of the backup wall.

Also worth considering in terms of acceptable rain leakage into the cavity, is the observation that the effectiveness of cavity flashing installation is extremely variable where discontinuities due to punctures and joints and lack of attachment to the backup wall allow water to accumulate on the shelf angle or run in behind the shelf angle. It is only common sense to build a brick veneer wall which is relatively impermeable to water penetration so that in most cases very little, if any, water will penetrate as far as the cavity. Design and construction measures to handle the water are necessary both for the small amount of water which penetrates most walls and for the cases where walls leak extensively because of faulty workmanship or other causes. However, the fewer the walls which are put to the ultimate test of extensive wetting, the fewer the walls which will experience distress due to rain penetration.

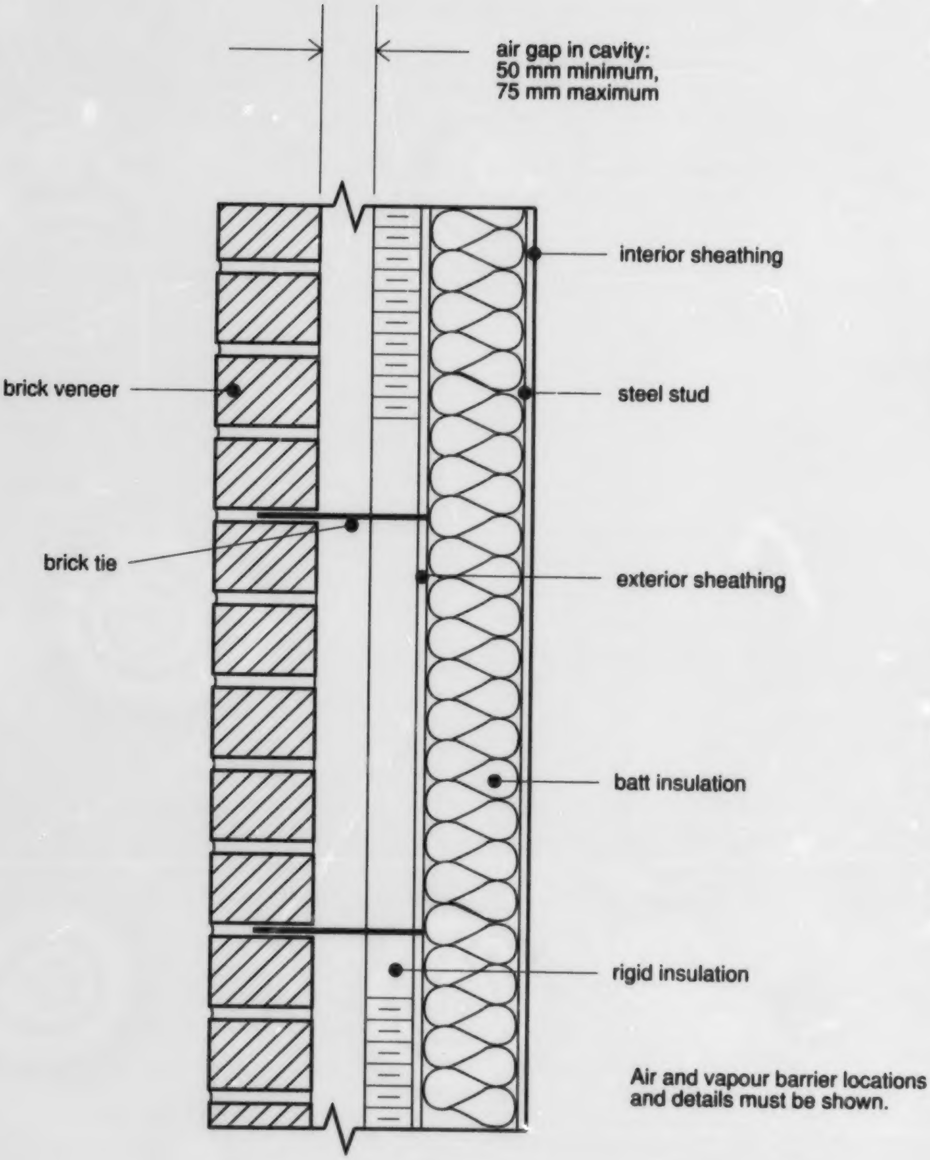
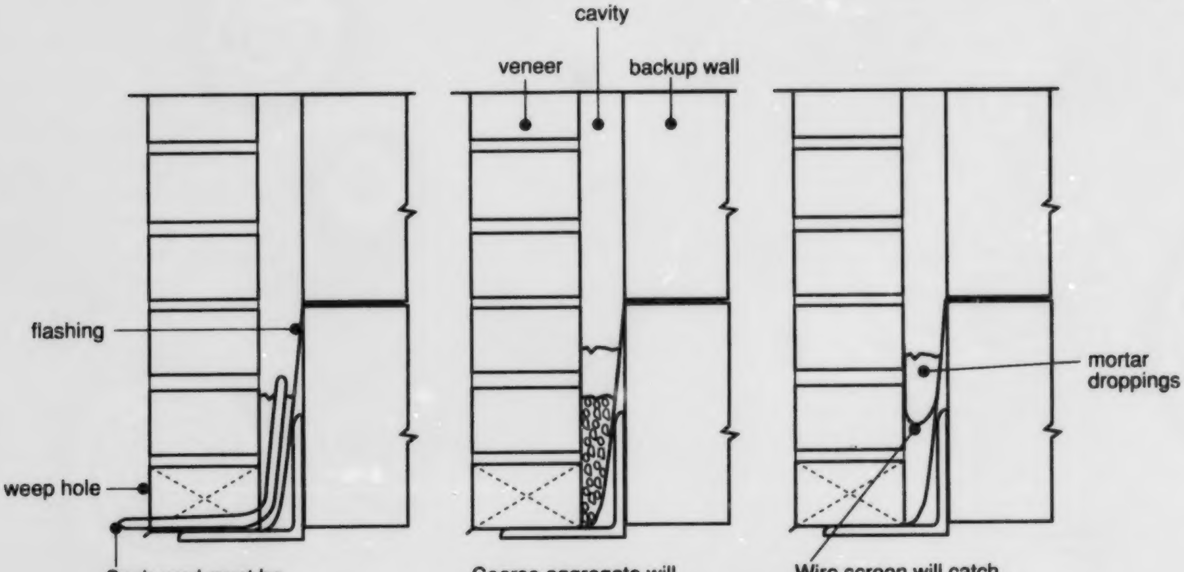

air gap in cavity:
50 mm minimum,
75 mm maximum
interior sheathing
brick veneer
steel stud
brick tie
exterior sheathing
batt insulation
rigid insulation
Air and vapour barrier locations and details must be shown.

Figure 8.5 Recommended air gap in cavity



Sash cord must be removed before mortar droppings harden.

Coarse aggregate will help keep drainage path open.

Wire screen will catch mortar droppings and prevent plugging of weep hole.

The most effective method of preventing plugging of weep holes is to minimize mortar droppings. Preventive measures include:

- Bevelling back mortar will reduce protrusion of mortar fins into cavity.
- A narrow strip of wood supported by wires can be lifted up the cavity as construction progresses. This will help catch mortar droppings.
- Rope laid at the base of the cavity and raised after the mortar droppings have partially hardened will help create a drainage path and prevent the mortar from becoming a solid mass.
- Bricks temporarily left out of the bottom course will allow the cavity to be cleaned out each day.

Figure 8.6 Methods of assisting drainage through weep holes

## 8.4 FLASHING

Materials used for flashing should be both impervious and tough so as to resist puncture and cracking. They should be sufficiently flexible to be readily shaped, cut, and joined to provide a continuous membrane for collection of water. They should not deteriorate when in contact with mortar, metal parts, or sealants and caulking. Sun light should not reduce their effective life.

Sheet metals, bituminous-coated membranes, vinyl sheets, laminated foil, or combinations thereof are currently used as flashing material. Acceptable bituminous membranes do not include asphalt-impregnated felt. Also, 0.15-mm polyethylene sheet and 30-gauge copper foil laminated to felt or Kraft paper are not recommended for use.

Although cost varies widely, the selection of flashing material should be based on suitability rather than cost. It is suggested that only superior materials be selected since replacement in the event of failure is extremely expensive.

Such high-strength material as sheet metal is often required since flashing is placed with the backup wall and is subject to wind with only inner edge support until the brick veneer is placed. At the same time it must be flexible enough to adjust to the final shelf angle location.

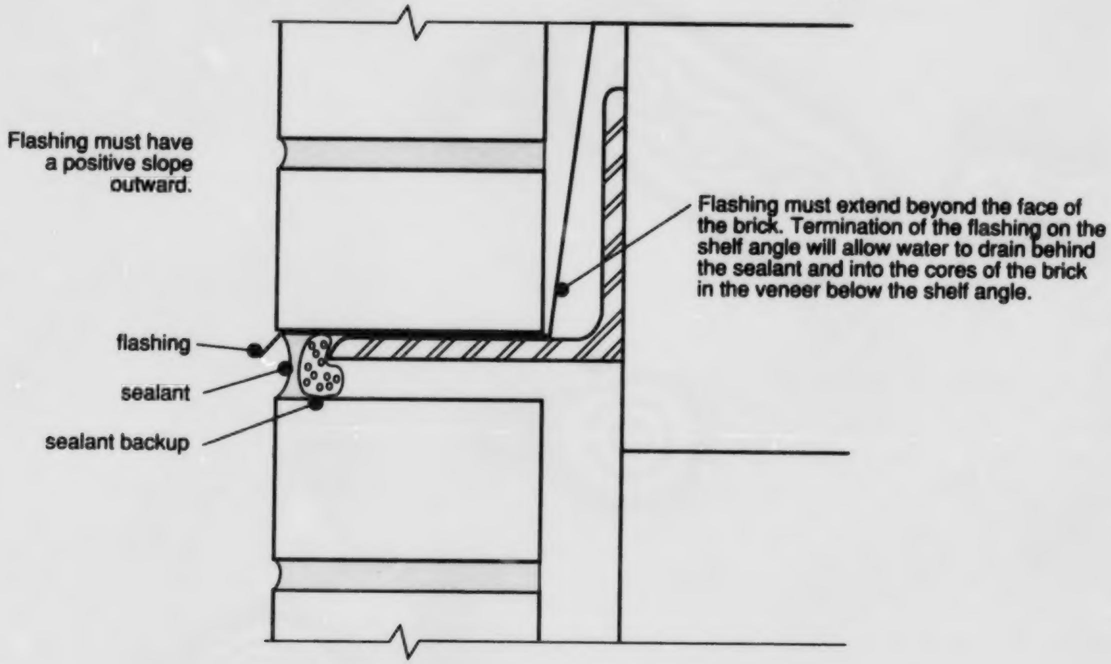
Flashing must be placed at any interruption in the wall such as at window and door heads, louvers or other wall penetrations, and sills as well as at shelf angle supports for the veneer. It is imperative that the flashing extend through the wall. It must not be stopped behind the face of the wall. Figure 8.7 illustrates both recommended and deficient flashing installation.

Because of lack of both clarity and sufficient details in the design drawings, flashings are often discontinued at the wrong locations or improperly routed as shown in Figures 8.8 and 8.9. Reglets are often omitted on column faces causing the flashing to be discontinued at columns as shown in Figure 8.10. Flashing must be comprehensively detailed. To be effective, flashings must be continued across columns and around corners. At joints, sufficient overlap of the flashing should be ensured and the joints sealed. For best results, sheet metal flashings should be soldered at joints, corners, and transitions. Because of misalignment of slab edges and the resulting reduction of design cavity width, the flashing may run into interference with the shelf angle anchor bolts as shown in Figure 8.11. An alternative route of the flashing, which can solve the problem, is also shown in Figure 8.11.

## 8.5 BACKUP WALL

In addition to structurally supporting the brick veneer, the backup wall provides support for the interior wall facing as well as the vapour, air, and thermal barrier functions. Typically, some components of the backup wall perform more than one function. As will be discussed in Chapters 9 and 10, regardless of the type of backup wall, there are different ways to satisfy these requirements where each concept has certain strengths and weaknesses.

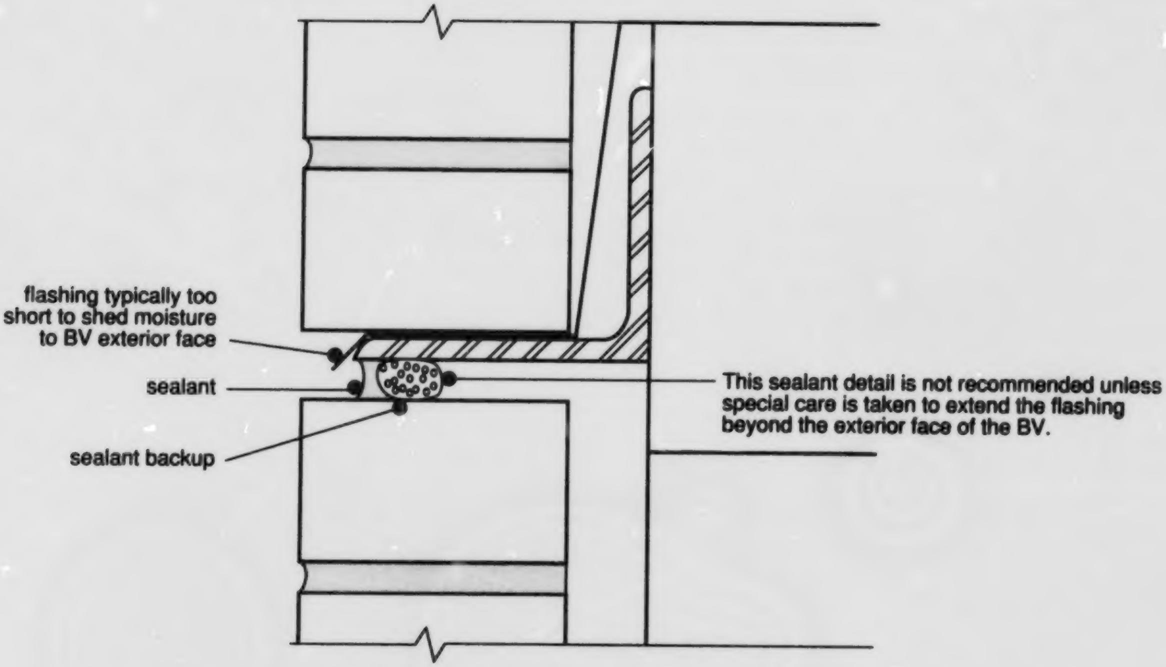
The backup wall is normally the support for window or door frames and can provide access for such services as electrical outlets. These or any other construction features that result in penetration of the wall can have significant effects on building envelope performance, principally because of difficulty in maintaining continuity of the air barrier.



Flashing must have a positive slope outward.

Flashing must extend beyond the face of the brick. Termination of the flashing on the shelf angle will allow water to drain behind the sealant and into the cores of the brick in the veneer below the shelf angle.

a) Recommended flashing and sealant detail



flashing typically too short to shed moisture to BV exterior face

This sealant detail is not recommended unless special care is taken to extend the flashing beyond the exterior face of the BV.

b) Deficient flashing and sealant detail

Figure 8.7 Flashing and sealant detail at a horizontal shelf angle joint

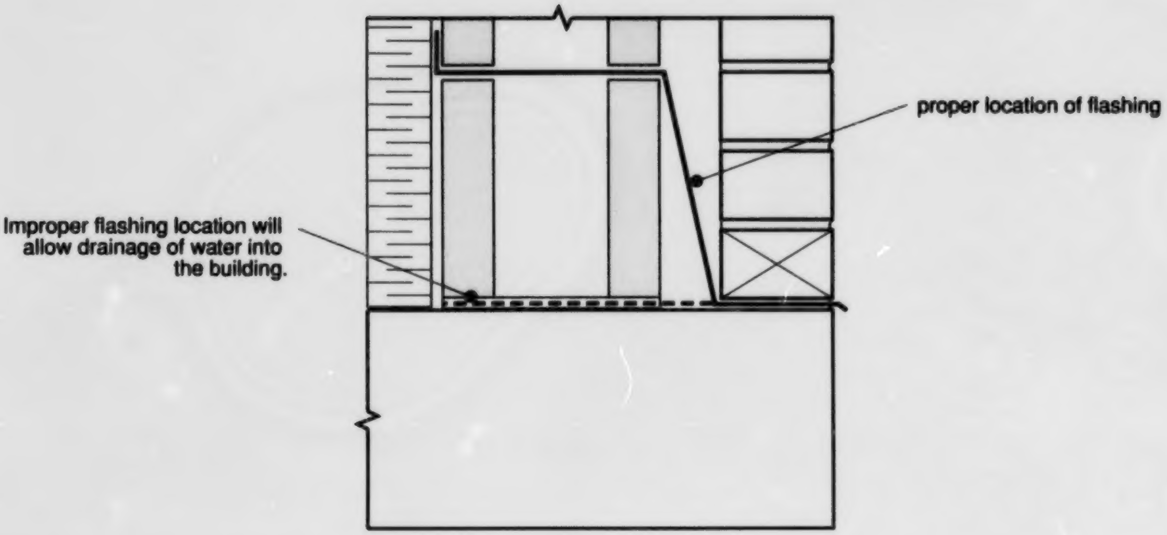

proper location of flashing
Improper flashing location will allow drainage of water into the building.

Figure 8.8 Flashing detail for veener supported on the slab

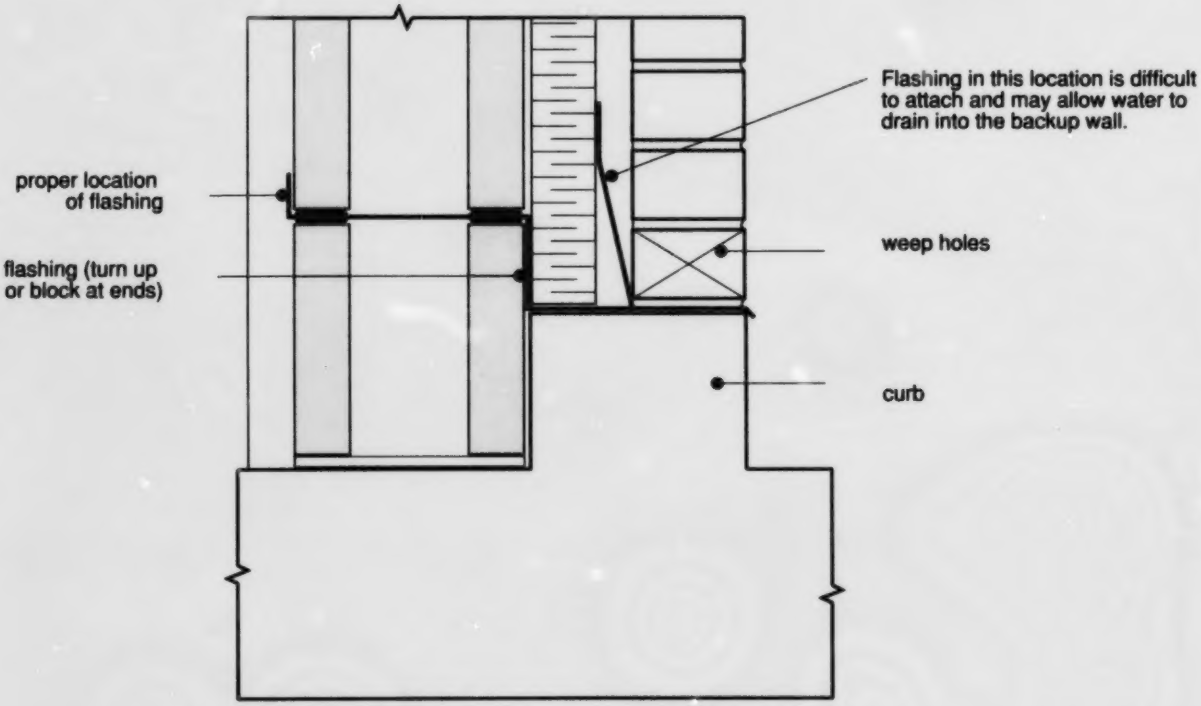

Flashing in this location is difficult to attach and may allow water to drain into the backup wall.
proper location of flashing
weep holes
flashing (turn up or block at ends)
curb

Figure 8.9 Flashing details at balcony ledge

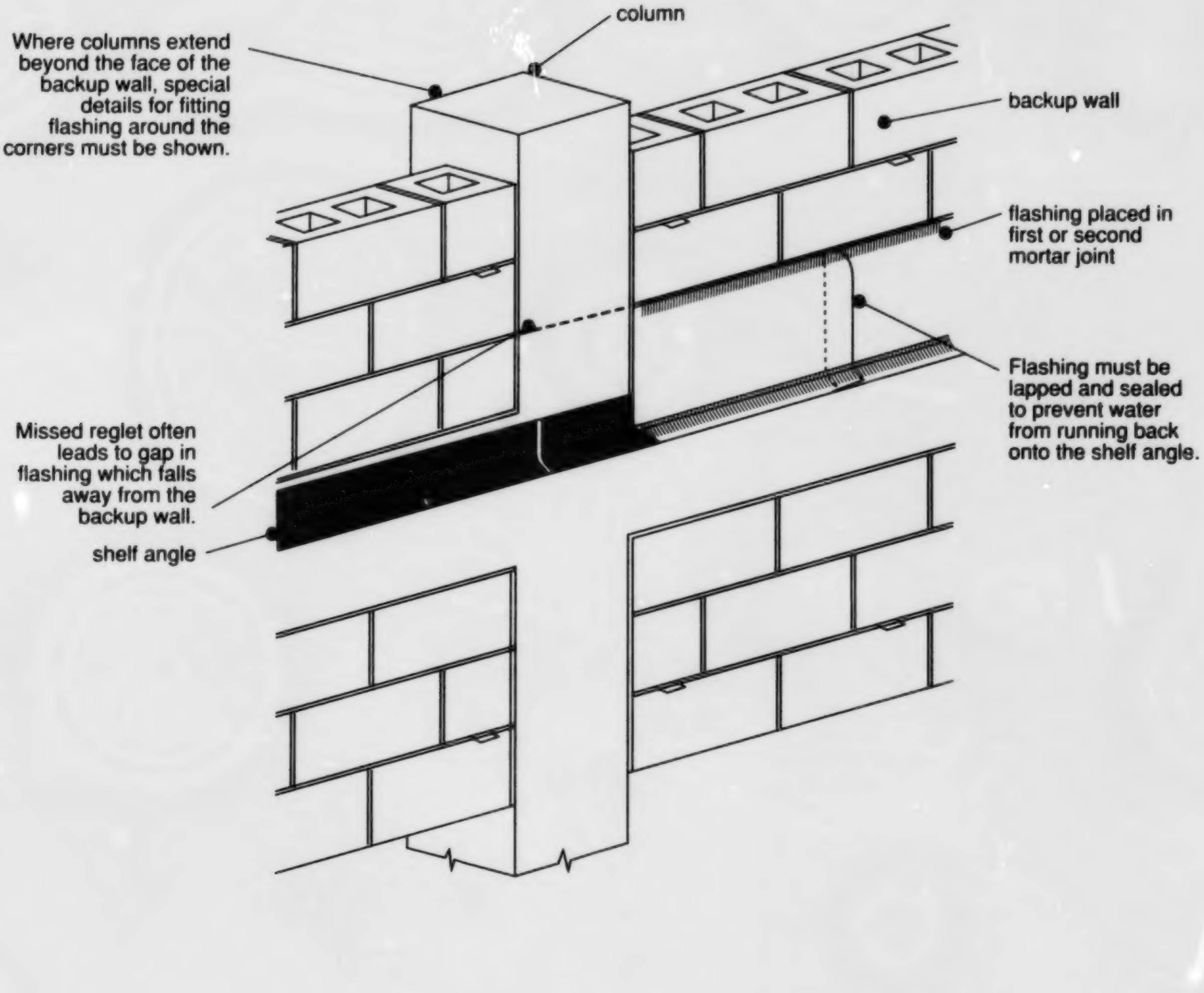

column
Where columns extend beyond the face of the backup wall, special details for fitting flashing around the corners must be shown.
backup wall
flashing placed in first or second mortar joint
Flashing must be lapped and sealed to prevent water from running back onto the shelf angle.
Missed reglet often leads to gap in flashing which falls away from the backup wall.
shelf angle

Figure 8.10 Detailing of flashing to maintain continuity

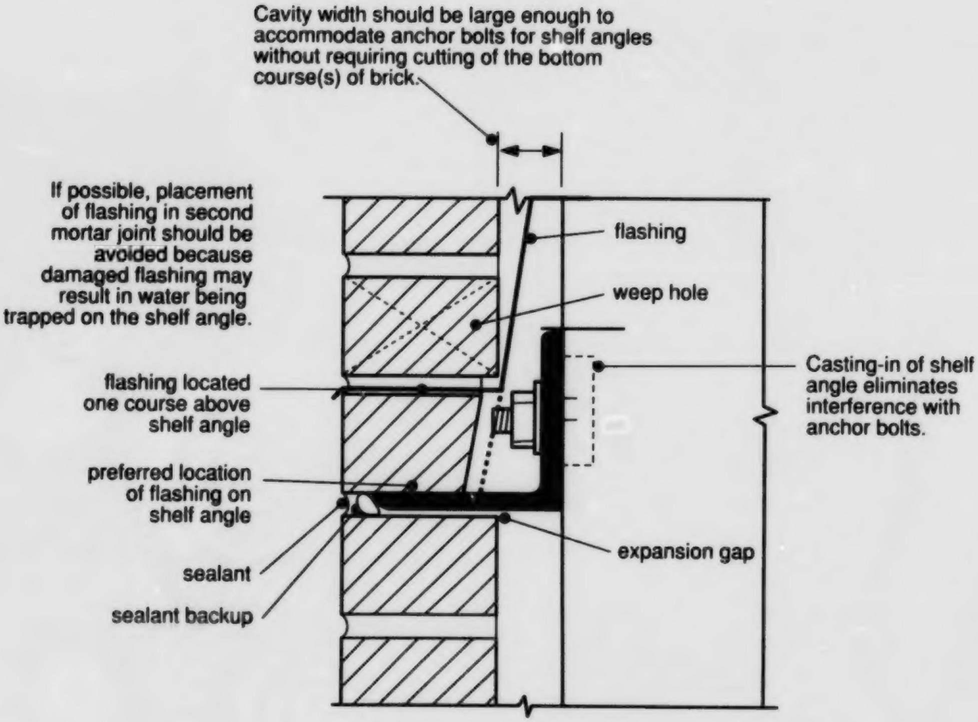

Cavity width should be large enough to accommodate anchor bolts for shelf angles without requiring cutting of the bottom course(s) of brick.
If possible, placement of flashing in second mortar joint should be avoided because damaged flashing may result in water being trapped on the shelf angle.
flashing
weep hole
Casting-in of shelf angle eliminates interference with anchor bolts.
flashing located one course above shelf angle
preferred location of flashing on shelf angle
sealant
sealant backup
expansion gap

Figure 8.11 Flashing raised above shelf angle to avoid interference with bolt

## 8.6 TIES

Ties are important structural components which have to be designed and installed so that they do not interfere with the building science functions of the wall. Because ties are normally installed before building the veneer, some adjustability to fit the level of the bed joints is an important feature. Otherwise procedures to lay out tie positions accurately must be employed.

Ties provide a potential path for rainwater to cross the cavity to the backup wall. Standard ties in accordance with CSA A370[11] do not have a drip because of the reduction of strength, but straight wires are not thought to be a significant source of moisture penetration provided that the ties are placed horizontally as indicated in Figure 8.12. However, where the ties act as a platform for mortar droppings, a continuous mortar bridge across the cavity can be a major source of wetting of the backup wall. Depending on the manufacturing procedure, wire or sheet crimped after galvanizing to create the drip could reduce the durability because of cracking of the galvanizing. Also, ties can be locations of easier passage of moisture through the brick veneer. This is particularly so where flat ties are simply laid on the bricks and covered with mortar rather than sliced into the mortar and fully embedded as shown in Figure 8.12.

Since ties are likely to exist in a moist atmosphere and may at times be wet due to condensation or rain penetration, it is essential that the durability of these key structural elements be assured either by providing corrosion resistance adequate for the situation or by using non-corroding materials. In addition, transmission of water across the cavity should be considered in the tie design.

The installation of ties may either puncture existing air barriers or cause difficulties in subsequent placing of this component. Therefore the method of attaching ties to the backup wall and the sequence of construction should be included in the choice of the tie. If required, construction specifications and drawings should clearly indicate the type of sealing or other repairs necessary at tie attachment locations.

## 8.7 SHELF ANGLE

Aside from the structural functions of shelf angles, there are several areas where building science-related functions can be affected. These are:

1. **Thermal Bridging.** Since the shelf angle is directly connected to the floor, some heat loss and resulting cold spots on the floor can result. However, as shown in Figure 8.13, extension of the insulation over the upright leg of the angle is feasible and will minimize this. Keeping the shelf angle and mechanical anchorage warm will avoid condensation and corrosion problems.
2. **Dimensioning and Aesthetic Considerations.** Since the thickness of the shelf angle does take up part of the height of the veneer, detailing for the overall thickness of the bed joints at the shelf angle must allow for a thin bed of mortar, flashing, the thickness of the shelf angle, and the vertical expansion joint. This has implications regarding the effect of a thicker joint on appearance and on the overall dimensions and coursing. Figure 8.14 illustrates this effect where a uniform appearance can only be achieved by use of a specially notched brick.

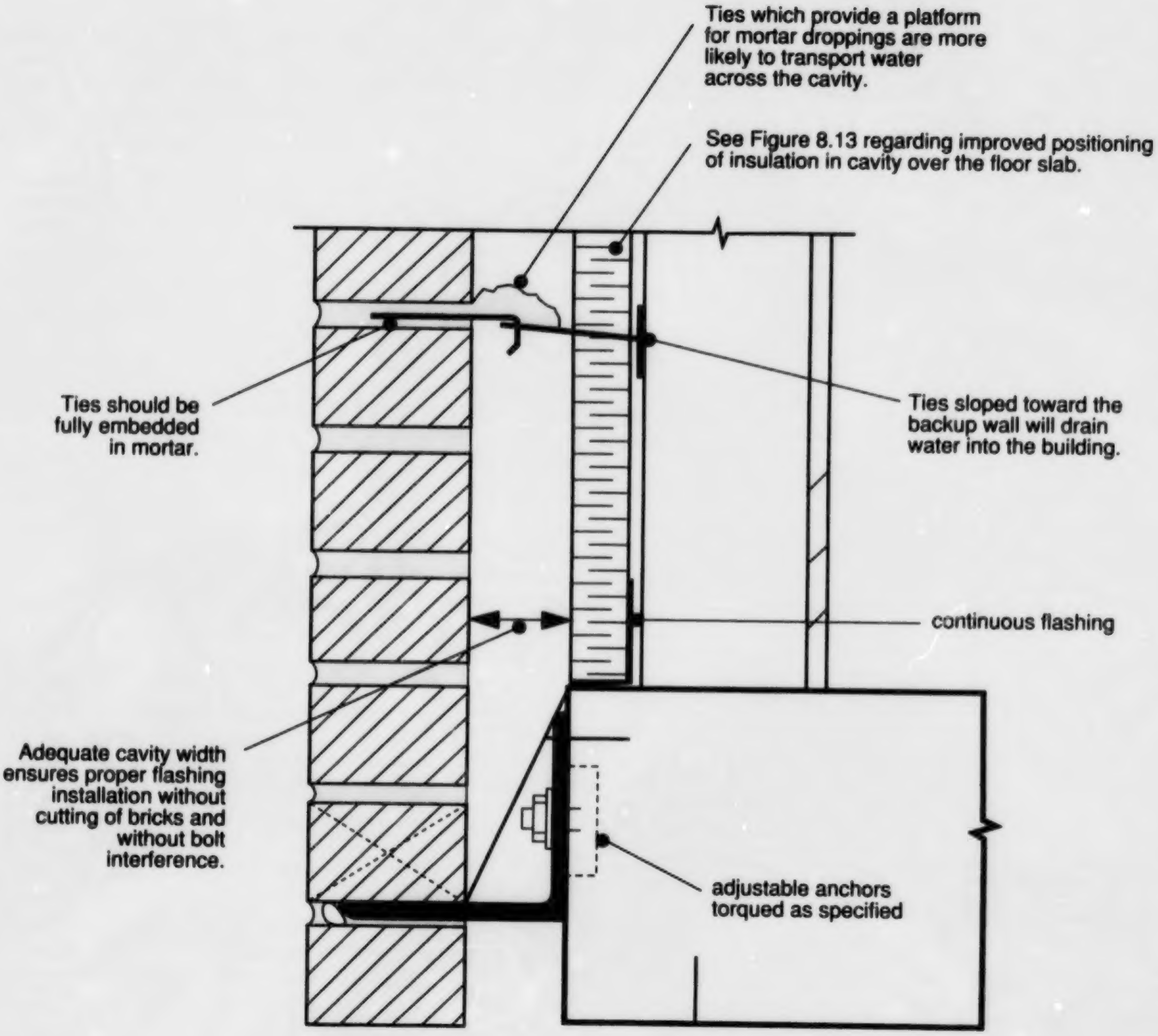

Ties which provide a platform for mortar droppings are more likely to transport water across the cavity.
See Figure 8.13 regarding improved positioning of insulation in cavity over the floor slab.
Ties should be fully embedded in mortar.
Ties sloped toward the backup wall will drain water into the building.
continuous flashing
Adequate cavity width ensures proper flashing installation without cutting of bricks and without bolt interference.
adjustable anchors torqued as specified

Figure 8.12 Potential paths for moisture penetration associated with ties

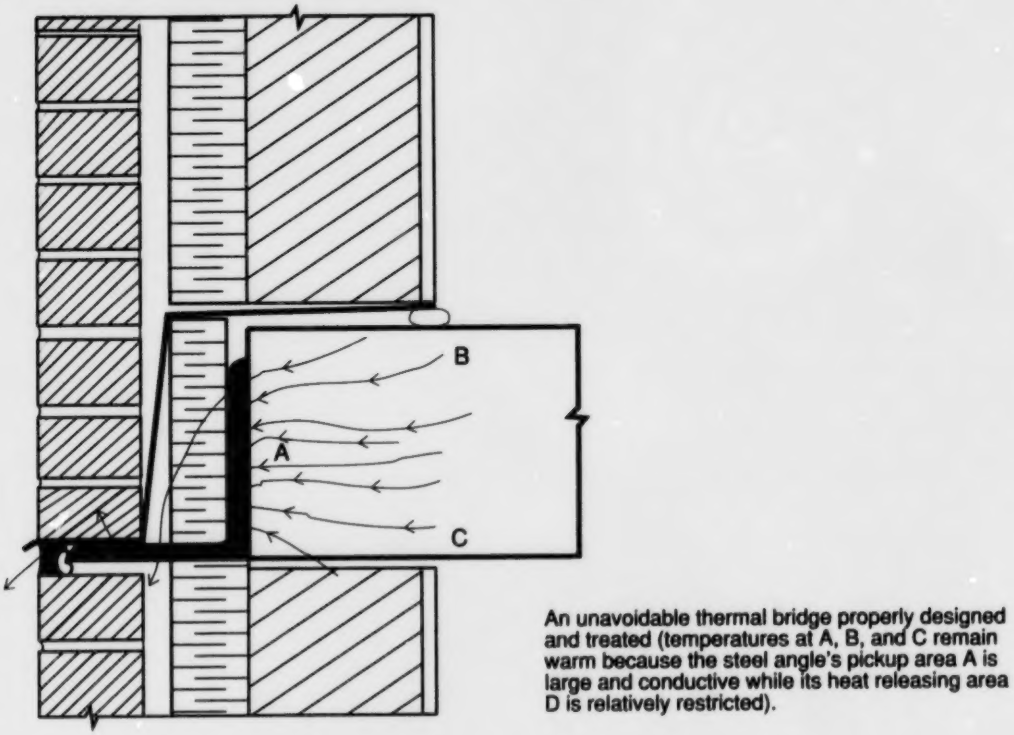
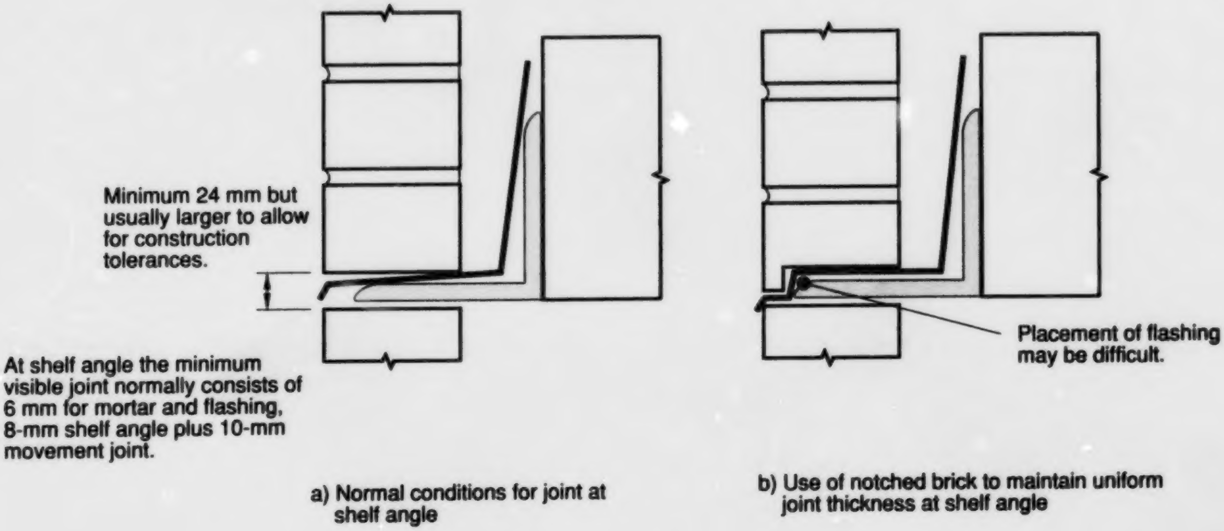

B
A
C
D
An unavoidable thermal bridge properly designed and treated (temperatures at A, B, and C remain warm because the steel angle's pickup area A is large and conductive while its heat releasing area D is relatively restricted).

Figure 8.13 Extension of insulation over floor slab and shelf angle to minimize the effect of thermal bridging


Minimum 24 mm but usually larger to allow for construction tolerances.
At shelf angle the minimum visible joint normally consists of 6 mm for mortar and flashing, 8-mm shelf angle plus 10-mm movement joint.
Placement of flashing may be difficult.

a) Normal conditions for joint at shelf angle

b) Use of notched brick to maintain uniform joint thickness at shelf angle

Figure 8.14 Thickness of joints in veneer at shelf angles

3. **Bolts.** Details must be developed to minimize puncturing of the flashing. Where the shelf angle is cast in with the slab, this problem does not exist.
4. **Flashing.** The flashing must be connected to the backup wall in a manner which will last for the life of the building. It must be positioned so that any moisture which might run down the outside of the backup wall will be directed out through a weep hole. In this regard, as shown in Figure 8.7 (a), the flashing must extend beyond the toe of the shelf angle so that backer rope and caulking form an effective barrier to having this water re-enter the veneer at the next level.

## *8.8 THERMAL INSULATION*

All the components of a wall affect the thermal resistance or overall R value. However, for brick veneer walls with either CM or SS backup walls, the insulating layer(s) provide most of the thermal resistance. Generally where circulation of air through the cavity occurs, neither the veneer nor the cavity contribute significantly to the total. Thermal bridging, for example, where the concrete slab is not insulated, should generally be avoided to prevent cold spots and condensation on the floor.[12]

The designer should choose the level of thermal resistance required as part of the rationale for determining the design location for the insulation. In this regard consideration should be given to the principle of diminishing returns where doubling the thermal resistance halves the heat flow but doubling that again only results in a further saving of a quarter of the original heat flow. When considered in terms of required air changes and the proportion of the wall with lower thermal resistance such as windows, there are logical limits to the amount of insulation. Methods of cost-benefit analyses are presented elsewhere.[13]

The possible locations for thermal insulation are:

- in the cavity;
- in the backup wall; and
- on the interior face of the backup wall.

The general types of insulation are:

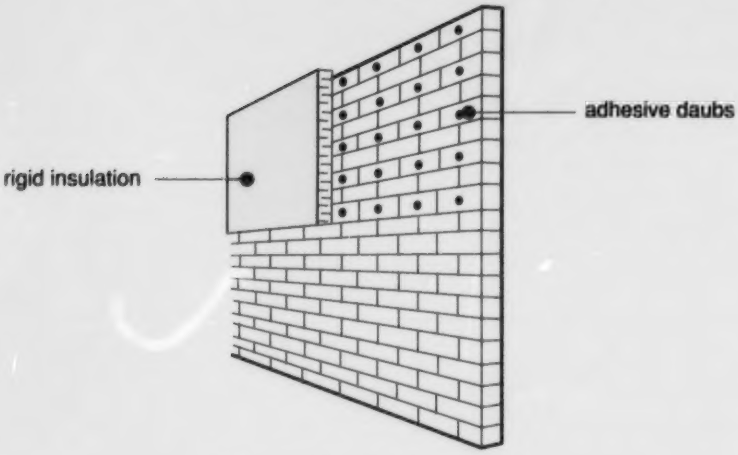
- rigid insulation;
- fibre batt insulation; and
- loose fill.

The choice of type and location of the insulation has significant implications for the overall construction process and particularly affects the design and construction of the air barrier and vapour barrier systems.

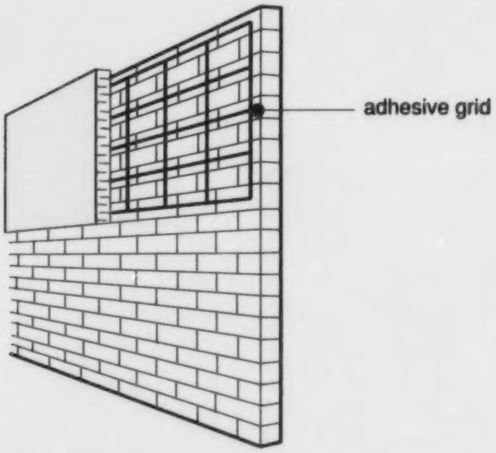
Where insulation is placed in the cavity, loose-fill insulation is not recommended because it may lead to water crossing the cavity more easily and it does not permit application of the benefits of pressurized cavities. Therefore rigid insulation boards are most likely to be used. For this to be effective, the insulation must be held tight to the outside surface of the backup wall. If even a small amount of air is allowed to circulate around the rigid boards, their insulating value is greatly decreased. Obviously, insulating boards that *float* freely in the cavity do not add anything to the thermal resistance of the wall. As a result, the method of installing and securing these insulating boards is very important. Generally, adhesives or mechanical fasteners are used.

Considerations regarding use of adhesives include:

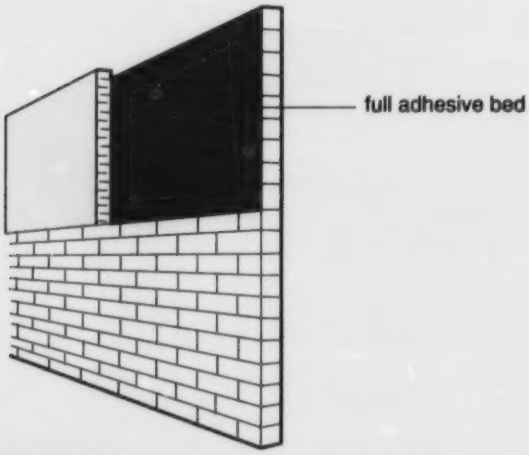
- difficulty with assuring clean adhering surfaces under on-site conditions;
- restrictions against use for exterior applications in cold or wet weather;
- need for compatibility of adhesive compound with the insulation; and



a) Not recommended



b) Better method



c) Recommended method

Figure 8.15 Application of rigid insulation with adhesives

- general stability and long-term effectiveness of adhesive, including general aging, attack by fungi and micro-organisms, cycling through temperature and humidity cycles, and repeated movements.

As illustrated in Figure 8.15, use of daubs of adhesive is not recommended because it creates an air gap which will allow air circulation. Use of a full adhesive bed is recommended, except where it may act as a vapour trap in which case a grid of adhesive is recommended because it will tend to compartmentalize the air spaces and retain the full benefits of this insulation.[14]

For mechanical anchorage, stick clips (see Figure 8.16) have been used. If the adhesive backing on the stick slip can be relied upon for the life of the structure, then this represents a simple fastening technique. However, mechanical connection using the ties as mounting devices (see Figure 8.17) or directly attaching the insulation to the backup wall by means of a screw and washer assembly as shown in Figure 8.18 are likely more reliable in the long term. Use of the mechanical anchors is essential where uneven surfaces or protrusions require compression or local bending of the insulation to avoid air gaps and the resulting decreases in thermal resistance.

It should be remembered that in addition to supporting its own weight and accommodating wall movements, the insulation can be subjected to significant wind suction pressures which must be resisted to keep the insulation in close contact with the backup wall. Therefore, choice of mechanical connection, adhesives, or a combination of both should take into account the expected life of the structure, the ability to conform to manufacturers' specifications (i.e., temperature or pot life for adhesives), and the consequences of failure of the connection. Thus, in some cases a combination of adhesives and mechanical connections may be advisable.

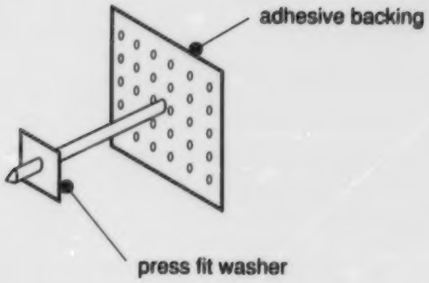

adhesive backing
press fit washer

Figure 8.16 Use of stick pins to mechanically attach insulation

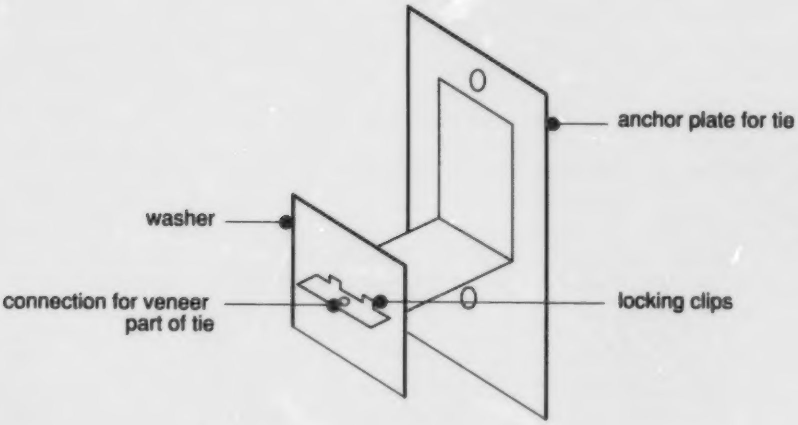

anchor plate for tie
washer
connection for veneer part of tie
locking clips

Figure 8.17 Mechanical attachment of insulation using ties

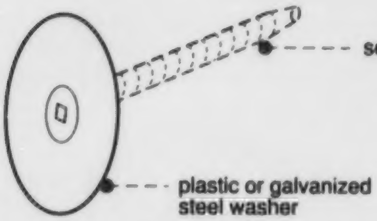

self-drilling screw
plastic or galvanized steel washer

Figure 8.18 Screw and washer assembly for mechanically attached rigid insulation

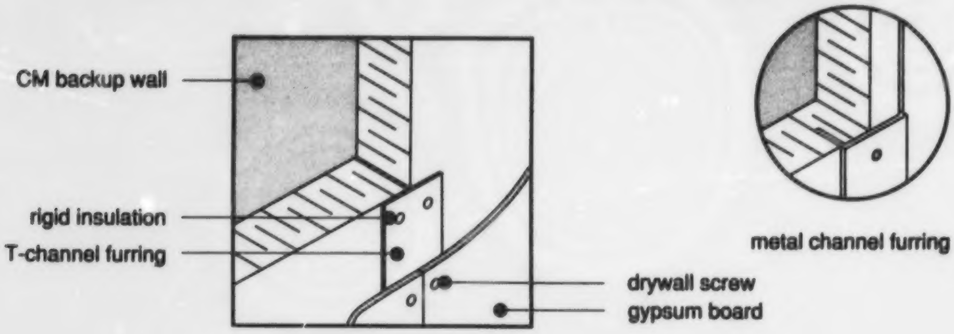
For current construction methods, use of insulation in the cavity requires that the wall be built in two stages with the backup wall built first. For low-rise construction this is not a major problem because of ready access from the outside. However, for high-rise construction, access by scaffold or swing stage may restrict the ability to inspect. In addition, for CM backup walls mortar fins must be removed to provide a smooth surface for close fitting of the insulation. The installation requires care for fitting around ties. Also, high-strength flashing may be required because of its potential for wind damage while exposed temporarily. Despite these considerations, the advantage of keeping the backup wall warm and reducing the effects of thermal bridges leads to the recommendation of placement of insulation in the cavity.

For insulation in the backup wall, this is normally loose fill insulation for CM backup walls, where, if additional insulation is used, the marginal benefit of the loose insulation is small. The exception could be for insulating cellular-type or lightweight aggregate concrete block where loose insulation or solid inserts could contribute significantly. For SS backup walls, the insulation is usually a *friction fit* thermal batt where the width of the batt is slightly larger than the stud spacing. Stud spacing must be carefully controlled so that friction is effective in keeping the batts in place. For this situation the batt must fill the entire inter-stud space so that air circulation is restricted. In this regard, it is necessary to specify both the R value and the thickness of the batt. Although the fibre texture of the batt is effective in limiting convection through the batt space, if the batt is surrounded by air space, convection can greatly reduce the effective thermal resistance.

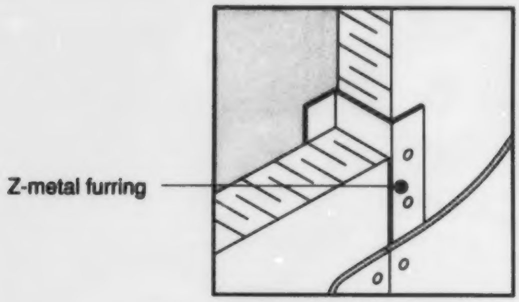
Use of insulation on the inside of the backup wall is normally limited to CM backup. It has the advantage of easy installation and inspection conditions. However, the thermal bridging through the floor and the cycling of the backup wall through the entire temperature range are substantial disadvantages.

The insulation may be fastened by adhesives or mechanical fasteners, but the need to support the interior wall covering often necessitates the use of metal or wood furring as shown in Figure 8.19.

It is important not to leave any gap between the insulation and the floor or ceiling. In case of hung ceilings or ceilings attached to the bottom chord of open-web joists, the insulation should be continued above the ceiling to the bottom of the structural slab as shown in Figure 8.20. For effective control of air and vapour leakage, air and vapour barriers should also be continued as illustrated. Besides, if the air barrier is not continued, the insulation may be separated from the backup by the pressure of infiltrating air as shown in Figure 8.21. As illustrated in Figure 8.22, proper butting of the edges of the insulation and attention to details at the air barrier can help minimize direct heat loss and other detrimental effects due to air exfiltration.

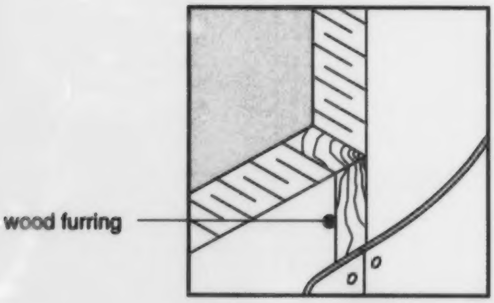

CM backup wall
rigid insulation
T-channel furring
drywall screw
gypsum board
metal channel furring

a) T-channel furring

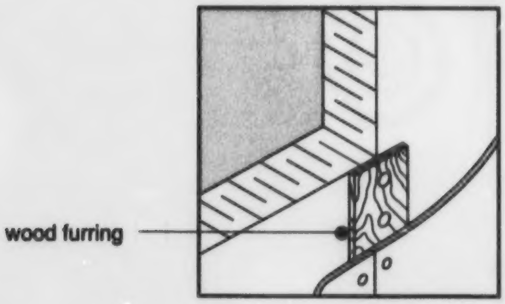

Z-metal furring

b) Z-metal furring

Note:
Furring systems b) and c) provide direct support for gypsum board to backup wall.


wood furring

c) Solid wood furring


wood furring

d) Wood furring

Figure 8.19 Furring systems

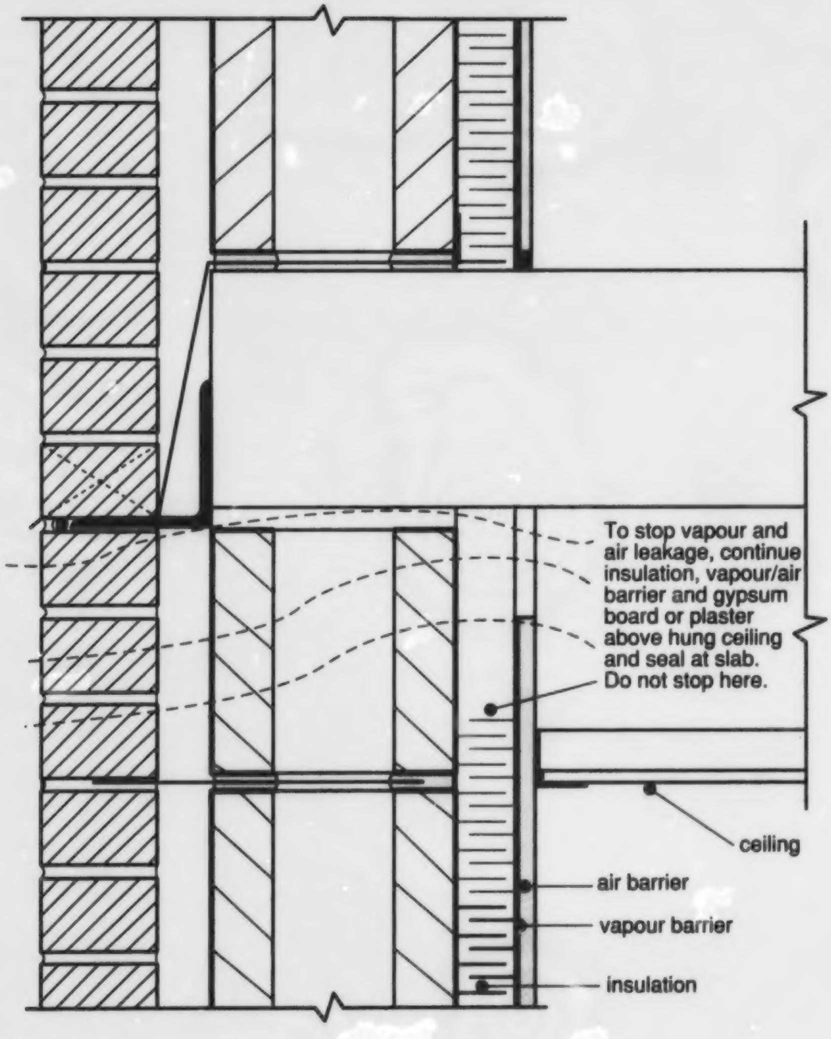

To stop vapour and air leakage, continue insulation, vapour/air barrier and gypsum board or plaster above hung ceiling and seal at slab.
Do not stop here.
ceiling
air barrier
vapour barrier
insulation

Figure 8.20 Illustration of the need to continue insulation, air and vapour barriers above hung ceiling

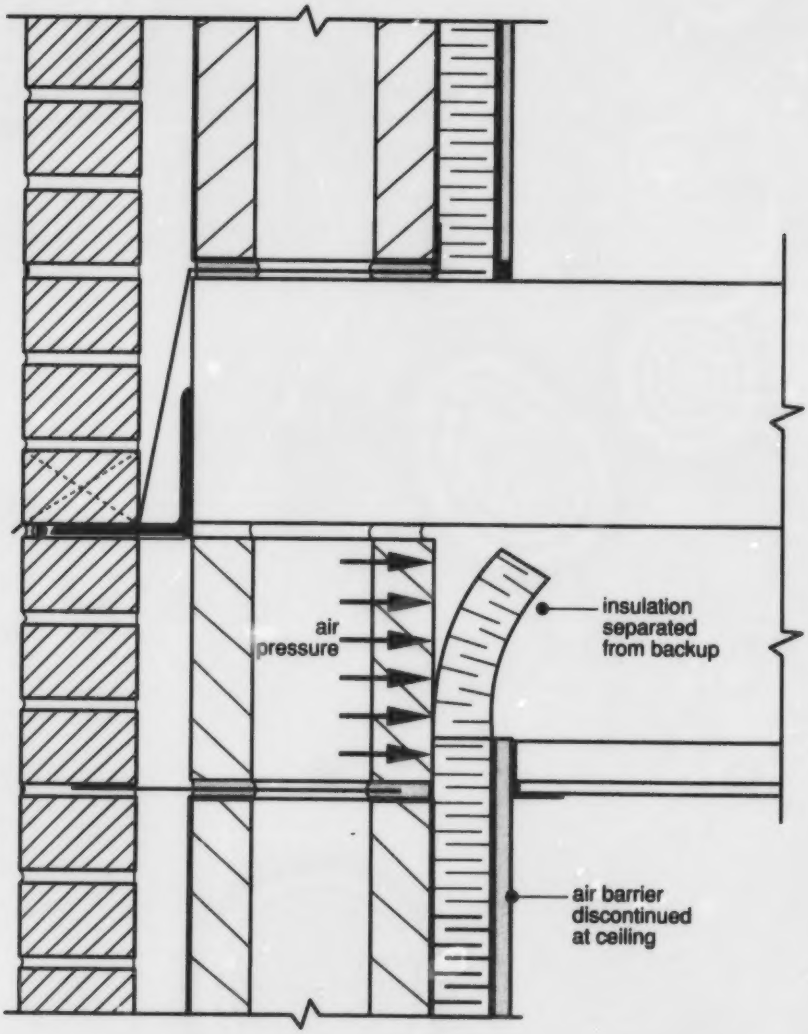
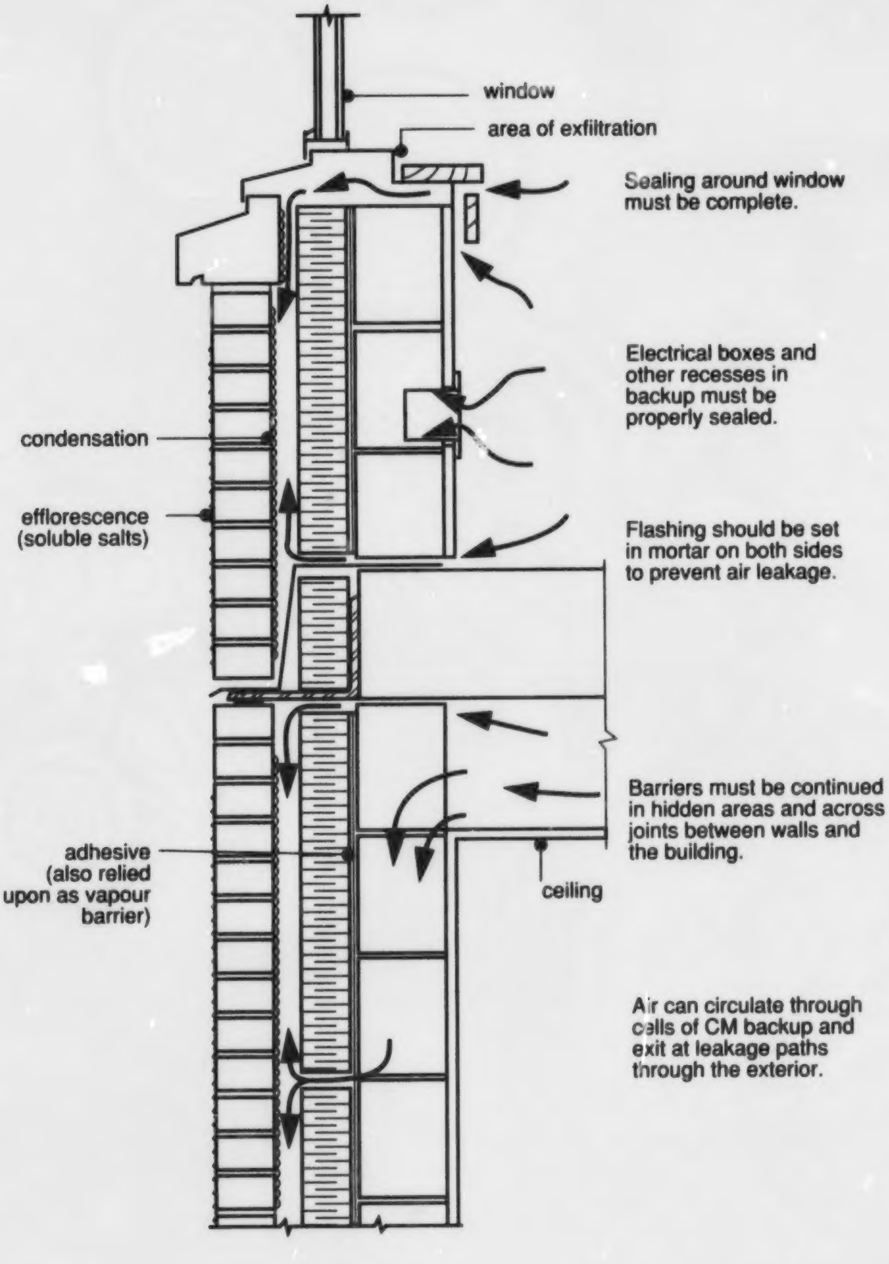

insulation
separated
from backup
air
pressure
air barrier
discontinued
at ceiling

Figure 8.21 Illustration of air pressure acting on unsupported insulation


window
area of exfiltration
condensation
efflorescence (soluble salts)
adhesive (also relied upon as vapour barrier)
ceiling

Sealing around window must be complete.

Electrical boxes and other recesses in backup must be properly sealed.

Flashing should be set in mortar on both sides to prevent air leakage.

Barriers must be continued in hidden areas and across joints between walls and the building.

Air can circulate through cells of CM backup and exit at leakage paths through the exterior.

Figure 8.22 Example of sources of exfiltrating air which may result in condensation of air borne moisture

## *8.9 AIR AND VAPOUR BARRIERS*

There has been some misunderstanding about the independent functions of air barriers and vapour barriers in that vapour barriers are intended to control transmission of water vapour through materials whereas air barriers are to limit the flow of air through the wall.[15,16] The cause of this misunderstanding may be due to the fact that it is very difficult to ensure that either barrier performs only a single function. For example, polyethylene film is commonly used as a vapour barrier, yet will also act to resist the flow of air when supported. Alternatively most types of sheathing used as air barriers tend to restrict the transmission of water vapour. Therefore a common problem may be that many wall assemblies contain essentially a double set of barriers.

If it is assumed that some degree of imperfection exists in the construction of the wall components — as inevitably will occur on site — then the design should be based on an evaluation of the potential deleterious effects of these imperfections. In practice this means that moisture may become trapped between barriers and, above all, that the degree of wetness and duration of wetness at certain critical locations may render designs vulnerable to premature deterioration and distress. That is, even though in theory these designs would function satisfactorily for conditions of perfect construction; in reality, flaws may be introduced which significantly reduce the long-term performance of the wall system. Of major concern to designers is the potential corrosion of steel components, weakening or deterioration of the sheathing material, and wetting of the insulation which will decrease its effectiveness and lengthen time of wetness of steel components. Growth of mold or fungus in the wall may also be an undesirable effect of trapped moisture in the wall.

Assuming inevitable construction imperfections, movement of moist air will occur through the wall and condensation will occur at the location of the dewpoint.

If the dewpoint is on the warm side of a barrier, there will be a buildup of condensation at this point with its resulting influence on insulation and sheathing material as well as corrosion of metal components.

Although it is generally agreed that the vapour barrier should be on the warm side of the insulation, there is currently no definitive argument for the correct location of the air barrier. Where the internal drywall or other finishes are used, there is concern that punctures for services, hanging pictures, and so on, plus incomplete sealing around the perimeter of the wall may all render it rather ineffective as an air barrier. On the other hand, use of an exterior covering on the backup wall has other liabilities principal among which is the difficulty with inspection or correction of faults and maintenance. Where air exfiltration does occur, the fact that the exterior air barrier has some vapour barrier qualities results in condensed water being trapped in the wall. However, walls designed with a sufficiently thick layer of rigid insulation outside of the exterior air barrier can be designed so that this second (partial) vapour barrier is also at a temperature above the dewpoint and hence should not cause a condensation problem.[17]

Tests, analyses, and field review have all demonstrated that the mass of water which can be carried into a wall by air leakage even through a very small hole is several magnitudes larger than the amount of water which is transmitted through a wall by diffusion.[18,19,20, 21] Therefore when the airborne moisture condenses, it is quite unlikely that this can be removed in sufficient volume by vapour transmission to the outside. In fact, drying out is more likely to be accomplished by dry air moving through the wall under different weather conditions.

The following quote from the *Guide to Energy Efficiency in Masonry and Concrete Buildings* supports that point of view:[22]

"In sum, it must be assumed, just slightly conservatively, that all the winter condensation accumulates in the envelope at least until the outer materials become saturated. After that, the excess condensation will run down and should be led outdoors through drains. Ventilation of the outer materials and/or their ability to breathe, as in the case of highly permeable materials, cannot be counted upon to help avoid saturation due to exfiltration/ condensation during the winter, although these measures or qualities can be useful in allowing faster drying in the spring."

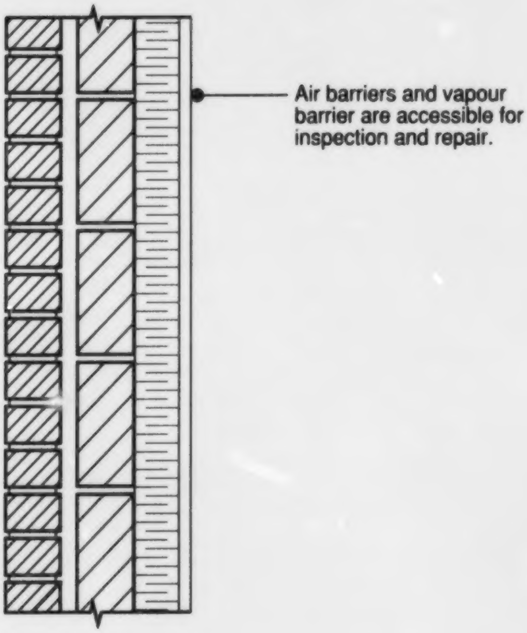

Air barriers and vapour barrier are accessible for inspection and repair.

Figure 8.23 Recommended locations for air and vapour barriers for construction where full-time inspection is not available

In general, the design of the air barrier/ vapour barrier system should aim to minimize gross errors and to tolerate minor errors. To some extent the choice of the location and quality of the air barrier/ vapour barrier design will depend on the quality of the structure and the type of client. Construction not subject to extensive inspection normally should have both the air barrier and the vapour barrier placed on the inside face of the backup, because faults can be repaired and it can be maintained more easily.

Therefore, it is recommended that the final visible interior surface be treated as the air barrier/vapour barrier as shown in Figure 8.23. Where full-time inspection is employed, the use of in-the-wall or exterior air and vapour barriers is probably more feasible. However, assessment of the suitability of the design for long-term performance should account for the fact that these barriers do not remain accessible to inspection or repair.

To help minimize significant deficiencies, a major educational program is required for tradesmen, foremen, and contractors as well as designers.

Typically, details and clauses in specifications do not address in-situ difficulties, and guidance is often lacking regarding:

- disruption of air barrier/vapour barrier systems by building services (e.g., electrical) or other wall components (e.g., ties);
- avoidance of concealed passages, such as above suspended ceiling, behind radiators, in cupboards, or at junctions with internal partitions which connect with interior and outer portions of the building envelope;

- minimizing and sealing joints in interior finishes;
- minimizing and sealing joints between interior finish and interruptions such as interior cross walls or windows; and
- painting or otherwise sealing interior surfaces.

A good example of in-situ difficulties can be found at window openings where field tolerance issues can have a major impact on the success of the continuity of the air barrier. In this situation, a variety of materials is used in a confined space complicated by such details as corners and affected by different trades, some of which do not understand the importance of the air barrier.

Where the components of the building assembly can be sealed to prevent air leakage and the interior finish provides the resistance to vapour diffusion, a separate vapour barrier is often not required. Otherwise, the best choice is usually polyethylene film which comes in large sheets and therefore minimizes the number of joints. It has advantages of high resistance to vapour flow, low cost, and if thick enough (i.e., ≥ 0.15 mm), it is reasonably resistant to construction damage.

Where cellular polystyrene or other rigid insulation is used as an air barrier, it is recommended that fully *buttered* joints on a full bed of adhesive be used on the outer surface of the backup wall.

## *8.10 SEALING*

To provide effective air and vapour barriers, it is usually necessary to seal joints in the barrier materials and to provide continuity around the edges and at such openings as windows, doors, or access for services. Normally either caulking or taping will be specified. In addition the joint should be fully detailed and dimensioned with due consideration of the need to accommodate large variations in joint dimensions, building deflections, and thermal movements.[23]

If the sealant material is to be built into the wall and thus hidden from later inspection and maintenance, it must have qualities which guarantee satisfactory performance over the life of the building, even when installation or service conditions are less than perfect.

Even where sealant materials can be repaired or replaced during maintenance, the sealant ideally should tolerate less than perfect surface and environment conditions and retain its adherence and elasticity over a long period of time. Field experience or test reports on long-term behaviour should be used as a basis for product selection from industry catalogues. Likewise, the feasibility and sequence of construction should be considered.

## 8.11 SEALANT, BACKING AND FILLER

Movement joints might perform their intended function best without any filler material in the joint. However, a seal is required to prevent the passage of liquids or gases through the joints without restricting the differential movement between the components being joined. A variety of sealing materials are available; the most common materials are one or two component, chemically cured, and polyurethane-, silicone- or polysulphide-based. It is the sealant which is the primary material that forms the seal; a backing and often a filler are used in deep movement joints particularly in masonry walls, to facilitate the formation of a proper seal. The sealing components of a typical movement joint are shown in Figure 8.24.

The successful performance of a joint seal over time depends primarily on the ability of the sealing material to adhere to the surfaces being joined and to deform without rupturing or peeling under repeated cycles of extension and compression. The shape and dimension of the sealant bead have a significant influence on this ability; a sealant bead concave on both sides and having a depth not more than half of the joint thickness is the best. Workmanship in application is also very important; inclusion of air bubbles in the sealant and of air voids between the sealant and the convex backing must be avoided. The sealant manufacturer's instruction should be followed for proper installation.[24]

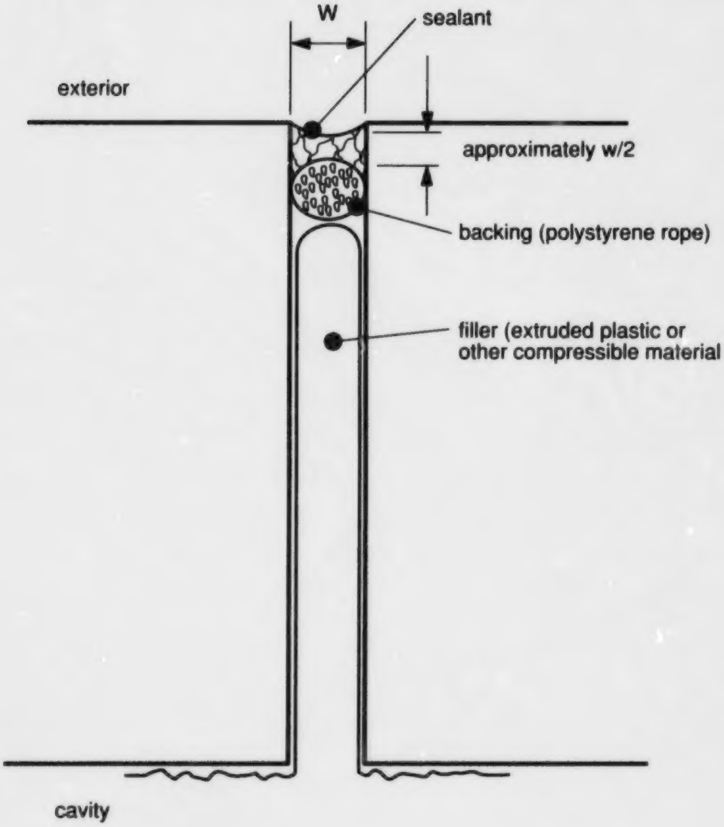
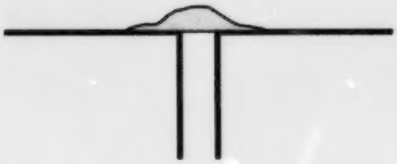

W
sealant
exterior
approximately w/2
backing (polystyrene rope)
filler (extruded plastic or other compressible material
cavity

Figure 8.24 Components of a joint seal

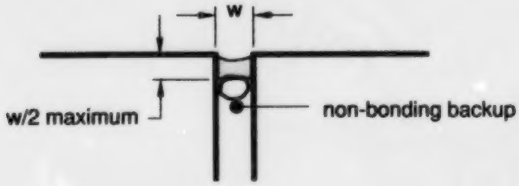
The function of the backing is to provide a base against which the sealant can be applied so that a sealant bead of proper depth and shape is formed. The backing should be at least as compressible as the sealant and must not bond with the sealant. Commonly a plastic rope made of closed-cell polyethylene foam is used as backing. Figure 8.25 contains sketches of a variety of sealant shapes and bond breakers. The design of sealant joints is discussed in detail in several readily available publications. To summarize briefly, the shape of the sealant bead has a considerable effect on its durability and performance. Sealing compound simply smeared over a crack is sure to fail because of the exposure of the material and the high concentration of stress at the crack (Figure 8.25 (a)).

The bead shape giving the least stress on the adhesion surface and within the material itself is one that is concave on both sides (see Figure 8.25). The curvature on the inner side is usually obtained by inserting a compressible plastic rope material, for example closed-cell polyethylene foam, that will not adhere to the sealant. The backup also serves to control the depth and uniformity of the bead cross-section. For proper application of a high-performance ± 25 percent movement capacity sealant, the joint should be a minimum of 6 mm wide, and the depth of the sealant should not be more than about half the width of the joint. However, more depth is recommended for low-movement capability sealants.

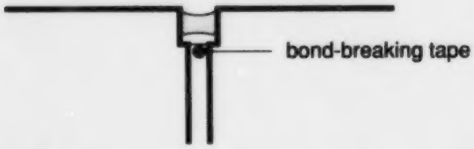
Joints having a square or rectangular backing (see Figure 8.25) are often used where expected movements are small or where the slot is too shallow for rope backup. But where possible, it is best to place a bond-breaking tape at the base of the joint.



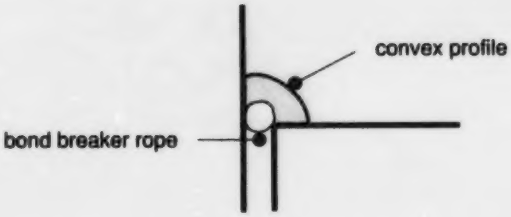
a) Unsatisfactory seal



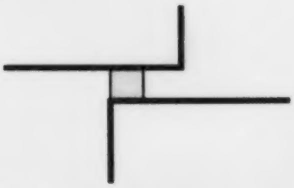
b) Best sealant shape for tension/compression



c) Rectangular joint



d) Fillet of controlled shape



e) Lap joint for shear movement

Figure 8.25 Sealant shapes and bond breakers

Fillet beads of uncontrolled shape are sometimes used where little or no movement is expected. Fillets required to undergo significant movement should have a convex profile and a bond-break in the corner to eliminate concentration of stress (see Figure 8.25).

Movement joints must be closed to exclude rain, snow, and dirt, and in some cases, to prevent air leakage. Generally this closure consists of a joint filler in addition to the sealant and backup material. Figure 8.26 shows a variety of joint fillers ranging from inexpensive asphalt-impregnated fibreboard to more costly copper.

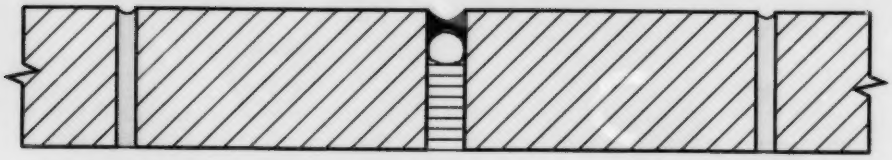
Both the filler and sealant must have enough flexibility to accommodate the repeated movement of the masonry into the joint and be able to rebound when the movement reverses.

Such filler material as asphalt-impregnated fibreboard, rigid polystyrene or other plastics, or solid rubber is capable of transmitting sizable compressive forces across the movement joints. Since transmission of forces across either vertical or horizontal movement joints negates the intent, these materials should not be used. An alternative to using a filler material is to use a second set of backer rod and sealant to provide improved air- and watertightness.

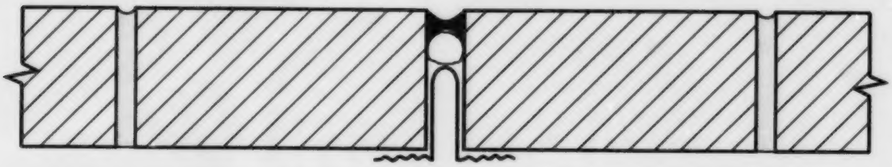
## *8.12 VULNERABILITIES*

It is recommended that every design should be subjected to a *vulnerability assessment* before a final decision is made. The vulnerability assessment should include:

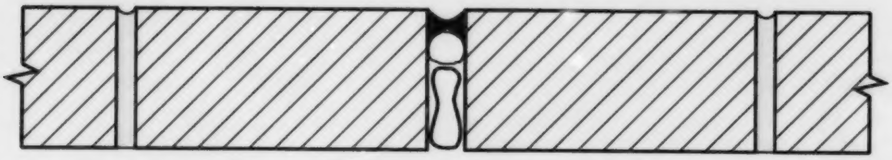
- extent to which design objectives (requirements) are satisfied;
- cost and occupant acceptance;
- adaptability to building tolerances;
- sensitivity to construction conditions (e.g., temperature, humidity, cleanliness);
- integration with other components (e.g., windows, interacting walls);
- construction sequence and interaction with other trades;
- constructability (e.g., simplicity and repeatability of details and minimization of components, dissimilar materials; and different trades);
- inspectability and ability to identify and correct faults during construction;
- long-term durability and life of components in the environmental conditions of the project; and
- ability to provide maintenance and to repair faults.



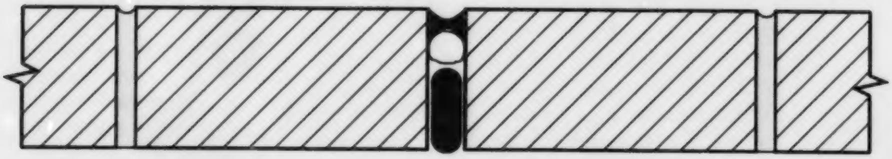
Asphalt impregnated fibreboard (not recommended because of resistance to compression and inability to return to original thickness)



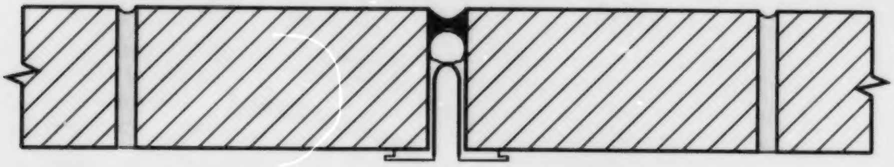
Extruded plastic



Neoprene



Premoulded foam rubber or plastic



Copper

Figure 8.26 Movement joint fillers

## *8.13 CONSTRUCTION*

Consideration of building science design issues referred to the vulnerability of a wall system to deterioration due to the effects of imperfections that must be expected in the air barrier and vapour barrier components of the wall assembly. From a contractor's point of view, a complementary concern is the degree of perfection which can be reasonably achieved. This will be very much influenced by the sensitivity of the materials and construction procedures to job site conditions. For instance, materials which are readily damaged, difficult to join or cut to fit openings, or which can be used only under certain temperature or moisture conditions are more likely to have construction faults.

The complexity or *fussiness* of the wall details can have a significant effect on the frequency of imperfections where, as a general rule, the best details are the simplest and those which are not highly sensitive to the *weakest link* for successful performance. For example, successful performance of the wall system should not be heavily dependent on the long-term performance of a single line of caulking located in a difficult to access area, which is later covered over. Similarly, the level of workmanship required particularly as it relates to special skills or special training of the workmen can adversely affect the effectiveness of a design. In general, it is desirable to minimize the number of trades involved in the construction of a wall.

Finally, the degree to which inspection can be effective is very important. If an aspect of construction requires continuous inspection because key features quickly become hidden behind other layers of construction, then this should be considered to be a weakness in the design. Unless use of the materials and the construction procedure are basically errorproof, a greater likelihood of construction deficiencies must be anticipated.

In much the same way, the ability to correct faults and to carry out regular maintenance should be among the foremost considerations when assessing the acceptability of a particular design. Although this is fundamental to many of the things we build, for some reason it does not seem to have been identified as a key feature for air barrier and vapour barrier construction.

## *8.14 KEY CONSTRUCTION REQUIREMENTS*

From the preceding discussion of building science requirements and additional considerations, the following key requirements for construction stand out:

- Good-quality workmanship must be used in construction of the veneer, so that full mortar joints tooled on the exterior face will be resistant to rain penetration.
- Mortar droppings must be minimized and weep holes must not be plugged so that moisture can drain from the cavity.
- Undamaged flashing must be securely anchored to the backup wall with properly lapped joints to achieve a continuous membrane to collect water and direct it out of the cavity.
- Flashing must be sufficiently wide to reach the exterior face of the veneer so that water from the cavity is returned all the way to the exterior.
- At shelf angle locations, proper installation of caulking on backer rod is required to prevent water entering the top of the veneer and the cavity.
- Installation of ties must not provide a direct path to carry water to the backup wall, and ties perforating exterior components of the backup wall must be sealed as specified.

- Shelf angles must not be tilted backward, otherwise water will accumulate rather than be directed out of the wall.
- Regarding installation of thermal insulation, gaps between insulation and other wall components and open joints between units of insulation must be avoided. Otherwise, circulation of air can drastically reduce the benefit of insulation.
- Where insulation, air and vapour barriers are hidden from view by subsequent construction, special care is required to assure that flaws that could allow exfiltration of moist air are repaired. Continuity must be maintained across all joints in these materials and at intersections with other building elements such as slabs, windows, and columns.
- Manufacturers' instructions for use of the specified sealant must be closely followed and only specified filler material should be used to avoid restriction of movement and distress due to buildup of stress.
- No materials may be substituted without the approval of the designer.
- Where materials are hidden from view by subsequent construction, thus making repair and maintenance very difficult, choice of materials for their long life must be a prime requirement.
- Work in progress must be adequately protected from damage due to weather or construction activities by other trades.

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## CHAPTER 9

# BV/CM SYSTEM: BUILDING SCIENCE REQUIREMENTS

### 9.1 INTRODUCTION

In this chapter, the specific influences on building science considerations of using CM backup walls will be discussed in relation to:

- design requirements;
- behaviour characteristics;
- construction considerations; and
- specific areas of vulnerability.

The concluding section of the chapter will provide an overview of the design options, including a review of the vulnerabilities and the construction requirements associated with each option.

### 9.2 PROVISION OF A WEATHER SCREEN

As discussed in Chapter 8, properly built brick veneer will be resistant to water penetration. Only small leakage paths exist. Also, subsequent cracking of the veneer should not be encountered where:

- the stiff backup limits out-of-plane deflection due to wind or seismic forces;
- adequate ties are used;
- adequate size and spacing of control joints are provided; and
- deflections of the supporting structure are limited.

Every effort should be made to ensure that the quality of the veneer is such that it will provide good resistance to rain penetration. Veneers which are said to *leak like a sieve* are obvious examples of poor workmanship or design and cannot be regarded as an acceptable standard of construction. Nonetheless, in order to handle water which may enter the cavity through the veneer or at other locations, the BV/CM wall must be designed as an open rain screen system. This utilizes pressure equalization of the cavity and relies on draining of the cavity to prevent water from entering the backup wall. Hence the requirements for a clean cavity and unperforated flashing described in Chapter 8 are applicable.

The overall design of the BV/CM wall system affects the construction process which, in turn, has an effect on the choice of materials. For a load-bearing masonry structure, where the insulation is not in the cavity, the brick and block wythes can be built together, thereby eliminating the need for scaffolding or a swing stage. This requires overhand laying of the brick veneer. Also, joint reinforcement or other non-adjustable ties may be used to tie the wythes together, provided that uniform coursing is maintained. Where insulation is in the cavity or where the structure is reinforced concrete or steel, the block backup wall is usually built first, then the insulation and the brick veneer, or just the brick veneer, are added.

In these cases, although joint reinforcement or other non-adjustable ties can and have been used, the problems associated either with bending these out of the way or laying up the course of brick immediately below have led to contractor preference for use of an adjustable tie where the piece that anchors into the veneer is placed after the appropriate course of brickwork is in place.

Regardless of whether adjustable or non-adjustable ties are used, interference and fitting of the insulation around them and interactions with the other wall functions must be considered. Also, tests have clearly indicated that all adjustable ties do not provide equal performance. Hence from a building science perspective, the ties should be sufficiently stiff and free of mechanical play to limit movement which could result in premature cracking, overloading of certain ties, or movements at joints which could damage caulking or other sealing provisions.

The flashing must satisfy the conditions outlined in Chapter 8, which include provision of sufficiently strong flashing to resist tearing in the wind before construction of the veneer. In addition, the flashing must be securely fastened to the backup wall. In this regard, the following comments are provided:

- The flashing should extend up the backup wall by 190 mm, if on the outside of the wall, or 100 mm, if on the inside of the wall.
- Where the flashing is on the outside of the block wall, attachment by adhesives or mechanical fasteners alone is not recommended because of the possibility of water running down between the block and the flashing.
- For flashing on the outside of the wall, it is recommended that the flashing be bent into and anchored a minimum of 15 mm into the mortar joint immediately above the first course of blocks as illustrated in Figure 9.1. The mortar joint may be raked out to allow the flashing to be anchored in place at a later stage of construction. If the wall is not parged, the flashing should be placed outward of the insulation up to the point where it is bent horizontally into the mortar joint. If parging is used, the flashing may be anchored beneath the first block as shown in Figure 9.2.
- Where insulation or an interior finishing layer are applied to the inside of the CM backup wall, the flashing may extend through the base of the wall and be fastened a minimum of 100 mm up the inside face of the block.

### *9.3 RESISTANCE TO HEAT FLOW*

Filling of the cells of standard hollow block with loose insulation may not add sufficiently to the overall thermal resistance of the wall to be cost-effective. Regardless, the main insulation will be rigid insulation on the exterior face of the backup wall or rigid or batt insulation on the interior. As discussed in Section 8.8, for the insulation to be effective, it is very important that it be held tight to either the inside or outside face of the backup wall.

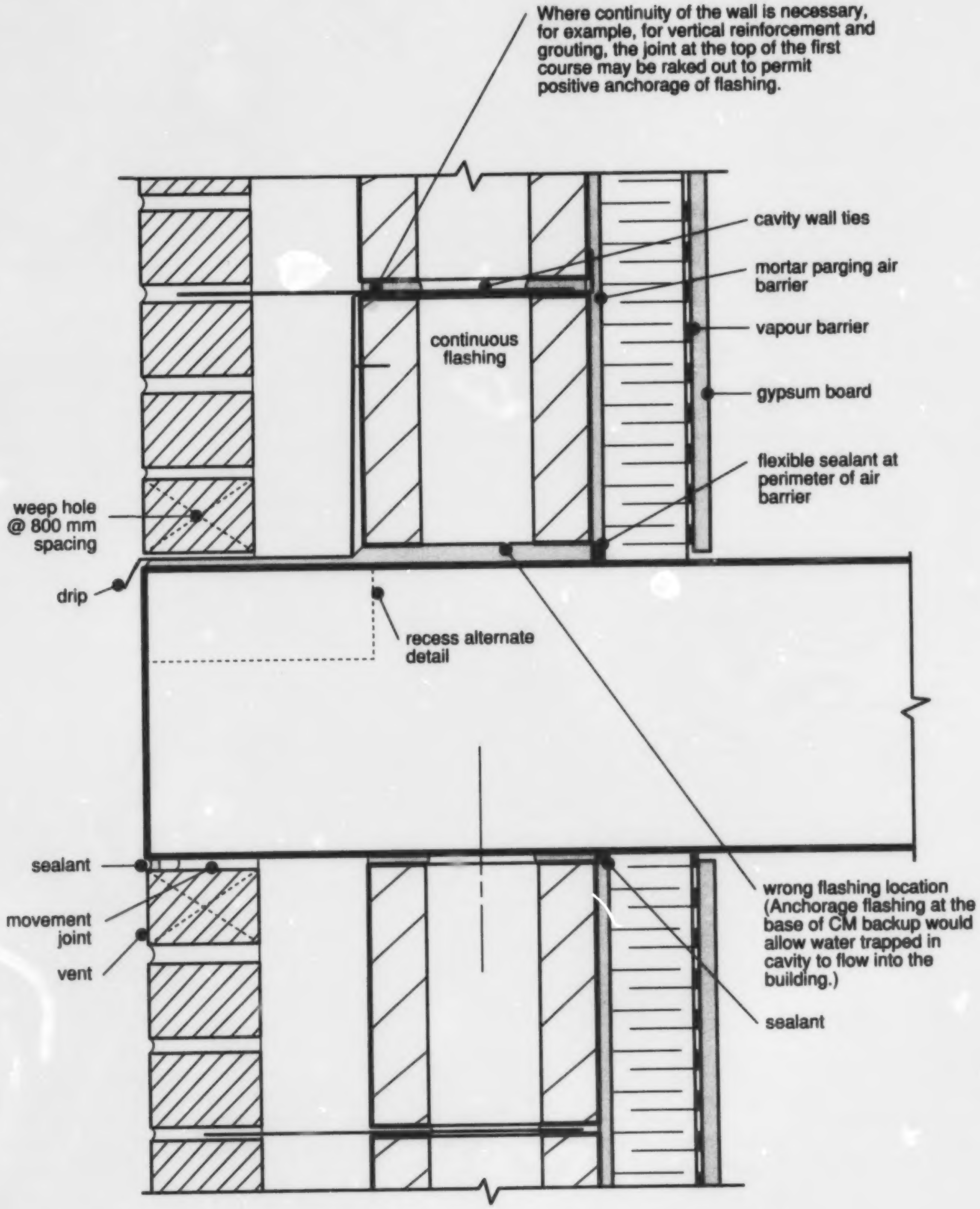

Where continuity of the wall is necessary, for example, for vertical reinforcement and grouting, the joint at the top of the first course may be raked out to permit positive anchorage of flashing.
cavity wall ties
mortar parging air barrier
vapour barrier
continuous flashing
gypsum board
flexible sealant at perimeter of air barrier
weep hole @ 800 mm spacing
drip
recess alternate detail
sealant
movement joint
vent
wrong flashing location (Anchorage flashing at the base of CM backup would allow water trapped in cavity to flow into the building.)
sealant

Figure 9.1 Flashing detail for CM backup wall

Depending on how smooth and flat the block wall is, it may be necessary to parge the surface to provide a smooth flat surface. Alternatively, air circulation behind rigid, cellular plastic insulation may be sufficiently restricted, if a full bed or grid of adhesive is used in addition to mechanical anchorage. Rigid, fibrous insulating boards may be sufficiently flexible that mechanical anchors can pull them into firm contact with the backup wall.

Given the mass of the block wall, standard ties will not create significant thermal bridging problems either in terms of heat loss or development of cold spots on the inside wall surface.

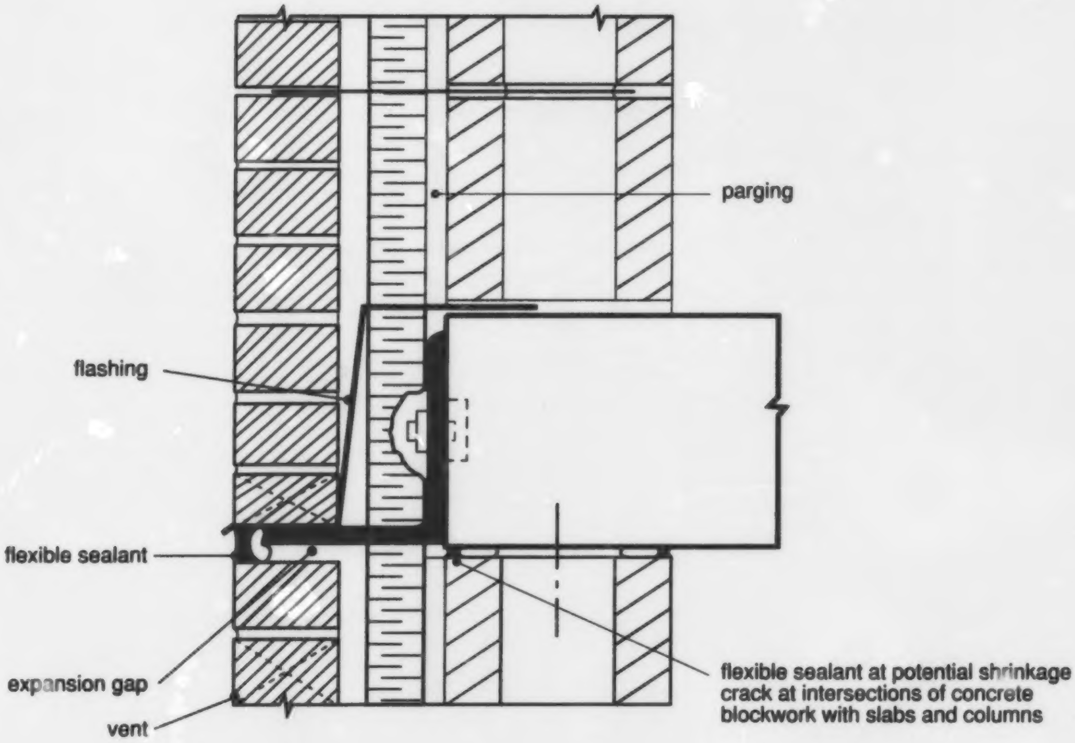

parging
flashing
flexible sealant
expansion gap
vent
flexible sealant at potential shrinkage crack at intersections of concrete blockwork with slabs and columns

Figure 9.2 Location and anchorage of flashing where parging is used on exterior of CM

## 9.4 RESISTANCE TO VAPOUR TRANSMISSION

For CM backup walls, there are four possible locations for the vapour barrier as illustrated in Figure 9.3.

**At the Interior Drywall or Other Interior Layer of Finishing.** This is necessary where insulation is placed on the inside of the backup wall. Depending on moisture conditions, the vapour barrier can take the form of:

- a painted surface on the gypsum board consisting of two coats of oil-based or alkyd paint;
- a 0.15-mm thick polyethylene sheet over the insulation; or
- the insulation itself, if it is sufficiently impermeable.

**On the Inside Face of the Block Wall.** Where the block wall is exposed, painting the wall or otherwise sealing it with materials which have high resistance to water vapour transmission can be effective. This surface covering material should also have some ability to span small cracks to reduce the amount of air which can penetrate to the cores of the block and, through convection, add to the potential for exfiltration of moist air in winter.

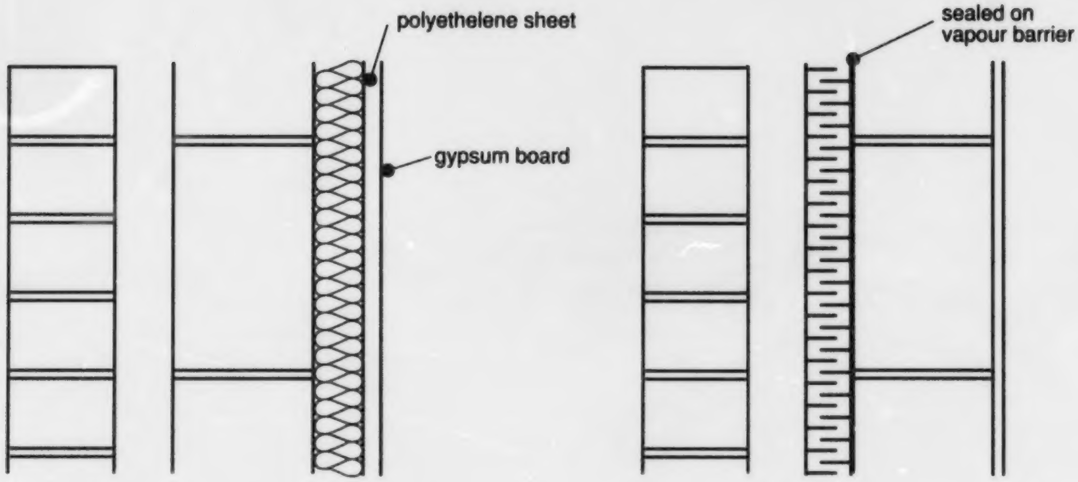
**Sheets on the External Face of the CM.** Where the insulation is placed on the outside face of the backup wall, the vapour barrier may take the form of a self-adhesive, torched on, or sprayed on impermeable sheet applied directly to the block. This layer must be continuous, able to accommodate moving cracks, and over the long term remain firmly attached despite air and vapour pressures and aging effects.

**Rigid Insulation Attached to the External Face of the CM.** Rigid insulation which has adequate resistance to water vapour transmission can be the vapour barrier, provided that it is held firmly in contact with the wall. In some cases, the mastic used to hold the insulation will itself form the vapour barrier, if the wall is covered with a full bed of adhesive. Alternatively, the joints between the rigid insulation boards must be fully *buttered* with adhesive, and provision must be made to accommodate movement around the edges of the panel.

## 9.5 RESISTANCE TO AIR FLOW

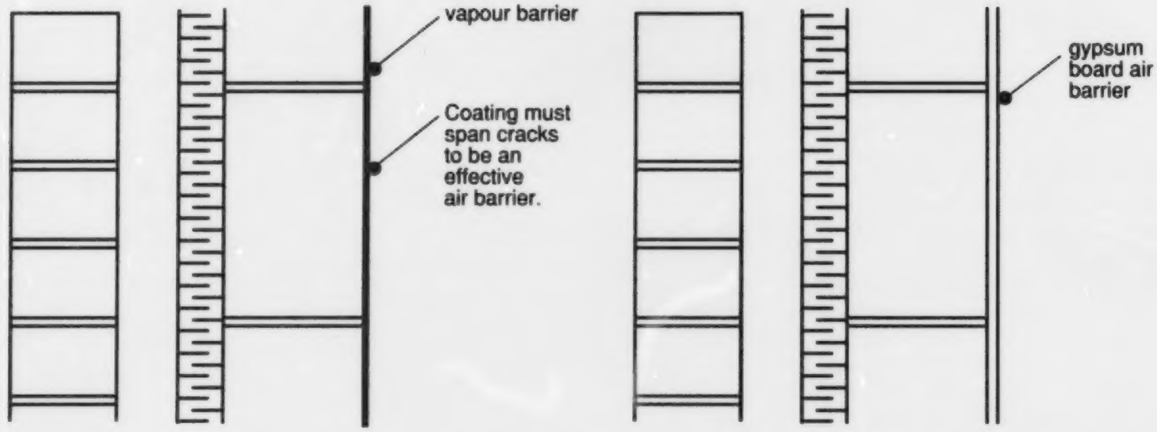
While block walls may appear to be a solid airtight form of construction, they have, in fact, characteristically high air leakage rates. Fortunately, CM backup walls are amenable to practicable and inspectable air-tightening measures which in general should be located inward of the dewpoint. The most common methods of creating airtight block walls are as follows:

- Parging of the exterior or interior of the block wall is effective in greatly reducing air leakage. This is the most common method of creating a reasonably airtight wall, but does require that special attention be paid to incorporating membranes or other permanent devices to continue the air barrier across movement joints at the top and sides of the wall.


polyethelene sheet
gypsum board
sealed on
vapour barrier

a) Polyethelene sheet serves as vapour barrier and gypsum board as air barrier.

c) Use of sealed-on vapour barrier can also serve as an effective air barrier where supported by insulation.


vapour barrier
Coating must
span cracks
to be an
effective
air barrier.
gypsum
board air
barrier

b) Interior coating serves as air barrier and vapour barrier.

d) Rigid insulation can serve as vapour barrier if properly sealed at joints and protected by air barrier on either the inside of the wall (gypsum board) or outside (parging).

Figure 9.3 Various locations of vapour barriers and air barriers for the CM backup wall system

- For an improved quality of air barrier through parging, the air barrier and vapour barrier may be considered a combined system where the parging provides an excellent base for application of the vapour barrier material. Then the vapour barrier material can effectively span reflective cracking, which may occur through the parging at mortar joints because of movement. In addition, the membranes or other devices to maintain continuity of the air barrier across movement joints can be integrated easily with this approach. External insulation will help support these membranes where they span movement joints.
- Interior gypsum board or other wall covering can be used as the air barrier, provided design and construction considerations outlined in Section 8.9 are followed. In general, even when the gypsum board is not intended to be the main air barrier, it is worthwhile taking steps to provide good airtightness in order to reduce air circulation in the cores of the block wall (see Figure 9.4).
- If interior or exterior rigid insulation is used as a vapour barrier, it may also be used to form part of the air barrier system where adhesion to the backup wall, fully buttered joints, mechanical anchorage to the backup wall, and provisions to span the movement joint provide a structurally sound and continuous barrier.

## *9.6 INTERIOR WALL COVERING*

Of importance to the overall suitability of a wall system is the adaptability (or acceptability) of the practical interior wall finishes. In some locations such as stairwells, entrances, foyers, and common rooms, surface-treated (painted) block or special architectural, split-face, ribbed, glazed, or coloured material may provide acceptable interior finishes. The thermal, vapour, and air barrier requirements must then, however, be designed on the exterior face of the block backup wall.

Often, painted or wallpapered gypsum board or plaster will provide the interior finish. Its support on furring and the taping of the joints for drywall provides a flat and continuous finish which, because of the furring, can readily accommodate electrical or other services. In such cases there are practical reasons for including thermal, air and vapour barriers as part of the internal system.

## *9.7 LOCATION OF WALL COMPONENTS*

From a theoretical point of view, location of the insulation, air, and vapour barrier on the cavity side of the backup wall is the correct decision in terms of minimizing thermal bridges and keeping the backup wall warm and therefore not having it subjected to the effects of thermal deformation cycles. Also, if the quality of the initial construction and the long-term durability of the materials can be assured, superior thermal insulation, air barrier, and vapour barrier materials or details can be used. This construction scheme also avoids in-use damage such as installation of wall-mounted fixtures and cracking due to building movement.

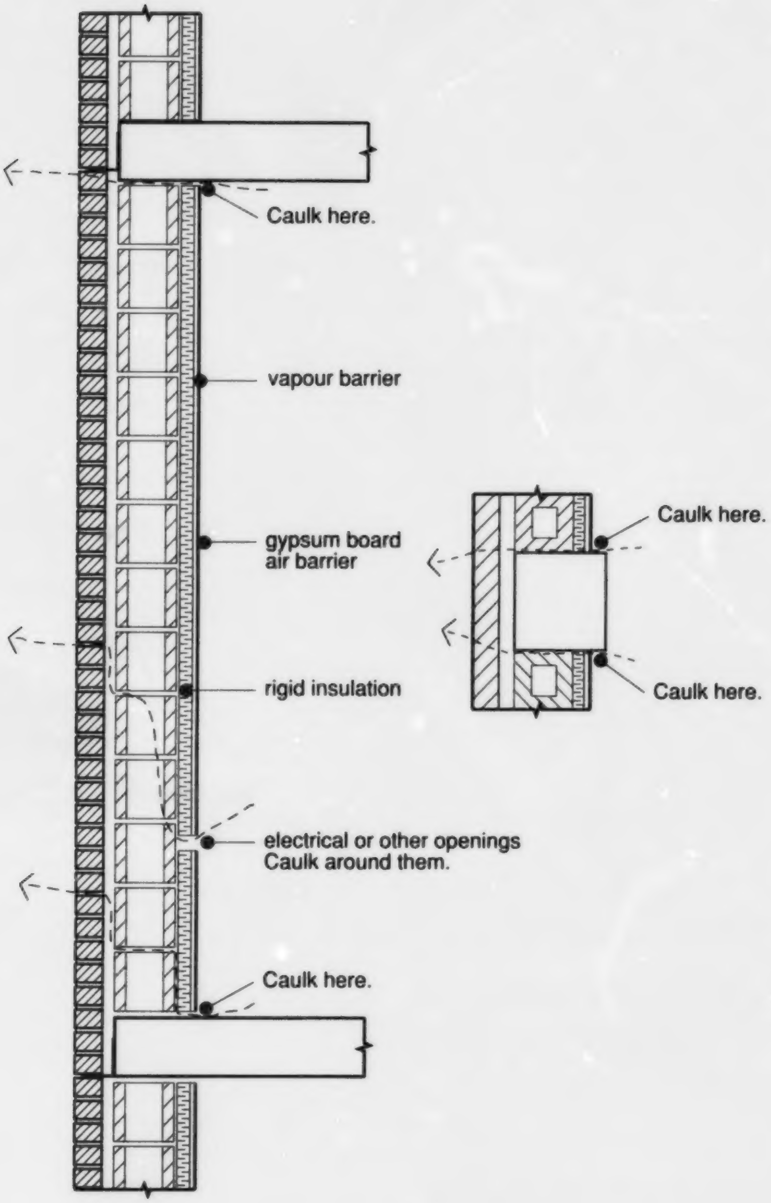

Caulk here.
vapour barrier
gypsum board
air barrier
rigid insulation
electrical or other openings
Caulk around them.
Caulk here.
Caulk here.
Caulk here.

Figure 9.4 Caulking locations in a gypsum board air barrier to reduce leakage

For high-rise construction, locating thermal insulation, air barrier, and vapour barrier on the interior face of the CM backup wall provides good construction access and is readily accessible for inspection. Also correction of construction deficiencies as well as eventual maintenance and repair measures are much more feasible than for designs where these wall components are located in the cavity. In addition, these barrier wall components can be installed by tradesmen more experienced and knowledgeable in these areas. Where windows, intersecting walls, and other components are installed later, maintaining continuity of the building envelope, particularly the air barrier, is fairly readily accomplished. Therefore, from a point of view of construction, there is a strong rationale for using this simple arrangement of wall components.

No universally applicable answer to this choice exists, and whereas the use of the potentially superior cavity location of the thermal, air and vapour barriers may be correct for certain types of buildings and clients, specification of the less efficient, but more repairable, interior location may be a more effective design for other situations.

## *9.8 VULNERABILITIES*

Every design should be subjected to a vulnerability assessment before final adoption. In addition to the general categories to be assessed as outlined in Section 8.12, the vulnerability factors unique to the use of CM construction are the following:

- Use of insulation on the inside of the CM wall increases the likelihood of cracking of the wall due to unintentional restraint to thermal movements.
- It is difficult to achieve an airtight seal on both face shells at joints. Therefore, air which leaks into the cells of the blocks can circulate through the units and exit at these joints.
- Shrinkage of the concrete block can result either in cracking due to restraint or in opening up of sealed joints as a result of shortening.
- Unless parging is used, the sometimes uneven surface of blockwork may make it difficult to place insulation tightly against the wall.
- For rigid insulation available in standard widths, the fixed positions of ties protruding from the mortar joints in the CM backup wall may cause difficulty with achieving, a tight fit at joints between the insulation. Use of joint reinforcement as the tie system may further complicate proper placement and continuity of the sheets of insulation, particularly where the joint reinforcement has been bent.
- When the BV and CM walls are built at the same time, mortar droppings from both sides of the cavity increase the volume of droppings and the possibility of impeding drainage of the cavity.

## *9.9 KEY CONSTRUCTION REQUIREMENTS*

From the previous discussion of BV/CM building science requirements and other considerations, the following key construction requirements for construction of the system stand out:

- Since the CM backup forms part of the moisture resistance of the wall, good workmanship regarding filling and tooling of mortar joints is required to achieve the intended airtightness and watertightness of the wall.
- Where parging is specified, it must provide a continuous surface at least 12 mm thick.
- At movement joint locations between the CM backup and the structure, sealing of these gaps requires special care to achieve continuity of air and vapour barriers.
- With the influence that cold or hot weather has on proper onside curing of mortars, parging and grout must be accommodated either by advantageous scheduling or by protection of new construction from detrimental weather conditions.
- Regardless of the location of the primary air barrier, joints and block penetrations must be sealed to prevent air circulation within the CM wall.
- Fastening of the insulation must ensure that the insulation is held tight to the backup wall and that continuity of insulation is maintained.
- To minimize shrinkage and assure improved bond, only dry blocks should be used in construction.
- Both during and after completion of masonry construction, the masonry must be protected from weather effects as specified in CSA Standard A371 (*Masonry Construction for Buildings*).

# CHAPTER 10

# BV/SS SYSTEM: BUILDING SCIENCE REQUIREMENTS

## 10.1 INTRODUCTION

In this chapter the building science functions of the wall will be discussed in terms of general requirements and how various features of SS backup walls specifically influence decisions regarding:

- design considerations;
- behaviour characteristics;
- construction requirements; and
- the impact of identified areas of vulnerability on these decisions.

The concluding section of the chapter will provide an overview of the design options including review of the vulnerabilities and key construction requirements associated with each option.

## 10.2 PROVISION OF A WEATHER SCREEN

Where the veneer is tied to a relatively flexible SS backup wall, the deflection of the BV/SS system at full design load can cause high flexural tension stresses in the brickwork. Whether the BV cracks will depend on the magnitude of the deflection and the flexural tensile bond strength between the mortar and the bricks. To design a SS backup to be sufficiently stiff to preclude veneer cracking altogether could make this form of construction uneconomical.

For this reason the following design approach is recommended:

- In designing the SS backup wall to carry the entire wind load, which it must do after the veneer has cracked, the deflection limits should satisfy acceptable masonry crack width criteria. A simplistic and slightly conservative method for prediction of crack width is illustrated below.

From Figure 10.1, if the lengths, $\frac{L}{2}$ of brick veneer on either side of a crack are assumed to remain straight, the geometric relationship between mid-height deflection on the veneer, $\Delta_v$, and the maximum width of the crack, $\Delta_c$, is

$$\Delta_c = 4\Delta_v \quad \frac{t}{L} \qquad \text{(Equation 10.1)}$$

where t is the thickness of the veneer.

Then, if the allowable deflection for

$$\Delta_v \text{ is } -\frac{L}{C}, \quad \Delta_c = \frac{4\,t}{L} \quad ,$$

where design practice has tended to adopt C values between 360 and 720.

For example, if a deflection limit of

$$\frac{L}{600}$$

is specified for use of 90-mm thick brick veneer, the maximum width of the crack would be

$$\Delta_c = \frac{4(90)}{600} = 0.60 \text{ mm}$$

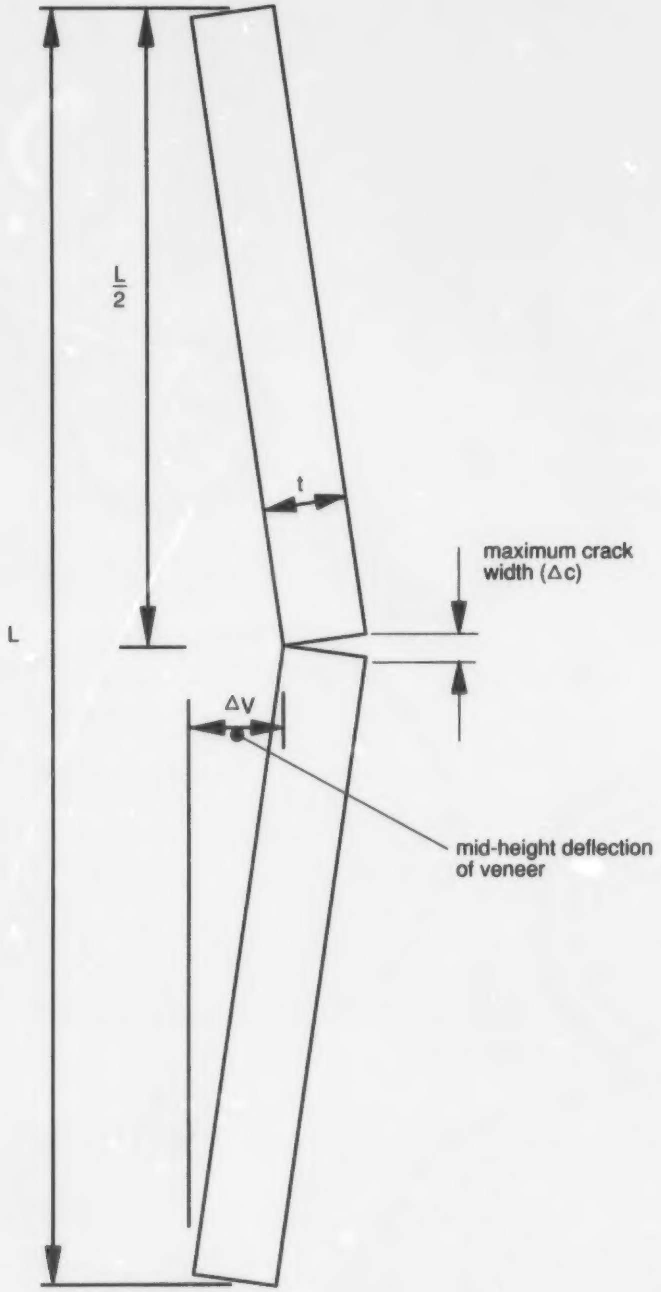

L
L/2
t
maximum crack width (Δc)
ΔV
mid-height deflection of veneer

Figure 10.1 Schematic drawing for simplistic calculation of crack width in brick veneer

At present, there are no serviceability criteria regarding allowable crack widths for brick veneer. However, it seems obvious and has been demonstrated[1] that cracking can result in substantial increases in penetration of wind-driven rain water. In addition to water penetration, there is concern that sufficiently large cracks could result in freeze-thaw damage. For lack of other information, the crack widths allowed in normal reinforced concrete can serve as a guide. Under service conditions, reinforced concrete crack widths between 0.1 and 0.2 mm are a maximum. Therefore, even if the average crack width is used as the basis, it would seem that an allowable deflection of $\frac{L}{360}$ resulting in a maximum crack width of 1 mm for a 90-mm brick or an average of 0.5 mm is a rather large value. For $\frac{L}{720}$ the average crack width of 0.25 mm is more appropriate, but it is still relatively large.

In view of both the previous discussion and the absence of crack width criteria for BV, the designer must select a design SS stiffness with due regard to the environmental conditions to be encountered by the structure. In general, it is recommended that the BV deflection not be more than L/720. (The deflection of the brick veneer will be affected by deformations and mechanical play in the ties, and displacement at the stud-track connection, as well as by bending of the steel studs.)

- Because higher rain penetration can occur for cracked veneer, in designing the BV/SS system there is an advantage to utilizing the inherent flexural strength of brick veneer to avoid cracking, except at very high loads.

  As a reasonable estimate, the veneer may be assumed to carry all of the wind pressure and to span from the shelf angle to the top tie. Alternatively, analyses which account for the two-dimensional behaviour of the veneer acting with the ties and SS backup will produce more accurate results. Where openings or other features of the wall result in significant horizontal as well as vertical bending, analysis of the three-dimensional behaviour is necessary both to determine how the load from windows or other openings is transmitted to the structure and to include the strength benefits of incorporating both horizontal and vertical bending.

As a guideline for design, it is suggested that the brick veneer be able to resist, without cracking, either the maximum unfactored positive or negative external wind pressures for cladding. For the fairly rare occurrence of combined full positive and negative pressures, the greater potential for cracking is deemed acceptable provided that the crack width is limited and overall structural safety is assured.

Analyses and tests have shown that for residential storey heights and good bond characteristics between bricks and mortar, cracking would not be expected under normal wind pressures of about 0.5 kN/m$^2$. In fact, if bond strengths of approximately 0.7 MPa are provided, wind loads up to about 1.25 kN/m$^2$ could be carried without cracking.

In addition to cracking, there are several aspects of construction which can affect the effectiveness of the weather screen.

### *BUILDING PAPER*

Construction according to Part 9 of the National Building Code calls for use of building paper on the exterior of the stud wall. The origin of this requirement seems to relate to wood stud construction where the exterior sheathing was protected from direct contact with water and where the joints between the sheathing were covered to prevent water from entering the stud wall.

In addition, the overlapping of this building paper may have served in part as an air barrier, and before placement of siding or veneer, the tar paper exterior also shed the rain water directly. Currently building paper over exterior insulation and on exterior drywall, while still potentially serving the same purposes, is generally not adequately secured to the exterior sheathing. Observations of poor practice, such as the use of roofing nails in rigid insulation or glue or tape as attachment to exterior drywall, illustrate a lack of recognition of the function of this material.

Where it falls away or is pulled off the backup wall by wind suction pressures, it may actually serve as a funnel to direct water that reaches the cavity across to the backup wall.

The ability of the backup wall to shed water should be a design consideration. Sheathing which is water-repellent and joints which are sealed (e.g., tongue and groove, glued or sealed with materials which maintain their properties over the long term) may well be sufficient without application of the exterior building paper. Alternatively, effective methods of attaching the building paper must be specified.

### *EXTERIOR SHEATHING*

Unless construction procedures are employed which ensure that water penetrating the veneer cannot cross the cavity (i.e., mortar fins and mortar droppings are removed), it is necessary that the exterior sheathing have some water-resistant properties, so that water will run down rather than be absorbed by the sheathing. In addition, when ties or other components puncture the sheathing, these areas should also be effectively sealed to exclude water.

Also, sealing of these paths is particularly important since ties may serve as cold thermal bridges and become potential locations of condensation of exfiltrating airborne moisture. Because of this potential availability of water, these areas require special attention to avoid corrosion and damage to the exterior sheathing.

### *FLASHING*

The flashing must satisfy the requirements discussed in Section 8.4. In this regard, when exterior building paper is not used over the exterior sheathing, the flashing should extend up behind the sheathing as shown in Figure 10.2. This can be an effective method for holding the flashing in place. When flashing is placed under the building paper or otherwise attached to the outside of the exterior sheathing, constructible details must be developed which assure that water cannot run down behind the flashing.

## 10.3 RESISTANCE TO HEAT FLOW

One of the characteristics of SS backup walls is that the inter-stud cavity can be used to house insulation, resulting in saving of floor area. In almost all cases, batt insulation is used between the studs where a friction fit keeps the batts in place. For batt insulation to be effective, convection must be avoided. Therefore the inter-stud space must be completely filled. Where double studs are used or where corners are formed, special attention is required to assure that the space enclosed between studs is filled with insulation.

Tests, analyses, and observations confirm that the thermal bridge formed by the steel stud does result during the winter in lower wall temperatures directly over the stud.[2,3] This can result in surface marking as well as heat loss. Additional insulation, usually in the form of rigid insulation on the exterior of steel studs, should be added to the wall for the following reasons:

- decrease overall heat loss by increasing the thermal resistance; and
- increase the temperature of the SS assembly by making it a *warm* thermal bridge. This eliminates interior surface marking and, because the steel components are warmer than the surrounding materials, condensation in the wall is less likely to accumulate on the steel components — particularly on screws used to fasten ties to the studs. For the rigid insulation to be effective, it must be attached in a way which will avoid air gaps between it and other exterior sheathing or between it and batt insulation where the rigid insulation is the exterior sheathing.

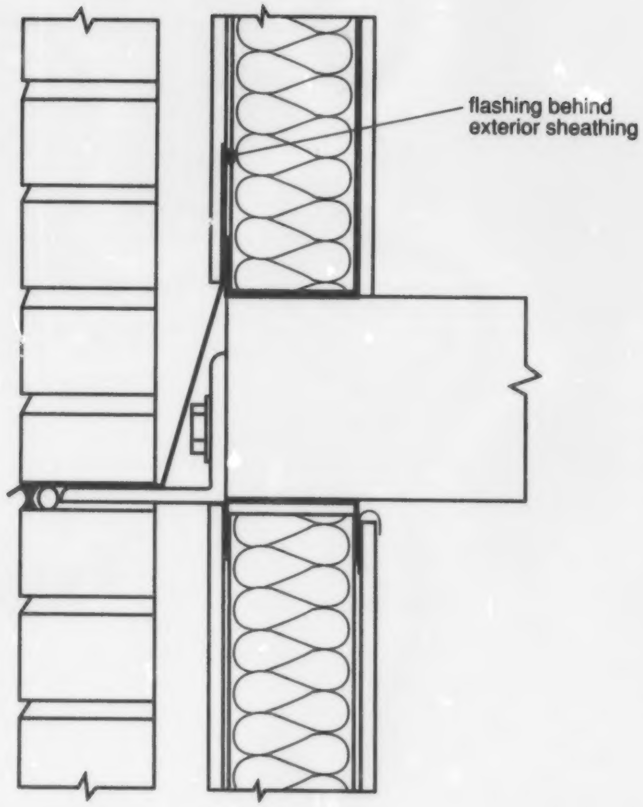


Figure 10.2 Location of flashing behind exterior sheathing

Figure 10.3 shows the thermal profiles for the stud line and the inter-stud space, both with and without exterior insulation.[4,5] The exterior insulation can be seen to be very effective both in reducing heat loss and in keeping the steel studs at temperatures above the dew point.

The exterior rigid insulation should extend down past the floor to provide continuous insulation over the full height of the building as shown in Figure 8.24. The rigid insulation must be attached back to the studs with sufficiently large washers or other load distribution elements to avoid the pull-through of screws in the rigid insulation.

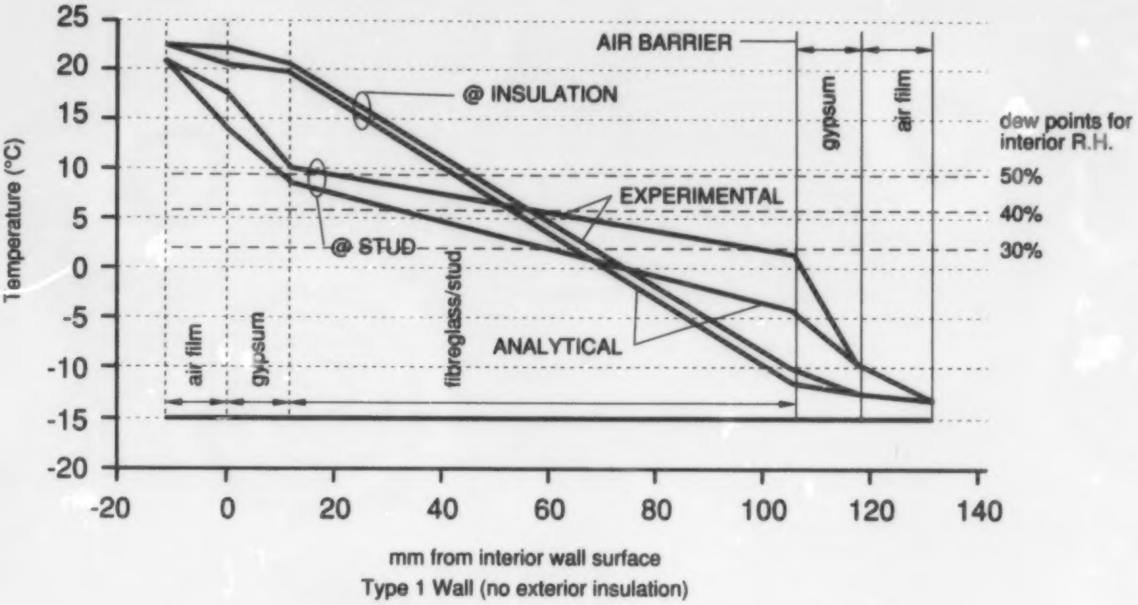
## 10.4 RESISTANCE TO VAPOUR TRANSMISSION

The vapour barrier should be on the warm side of the insulation or at least inboard of the dewpoint. For most applications, this means that the vapour barrier will be located on the inside face of the studs. The two most common forms of vapour barriers are:

- A 0.15-mm thick polyethylene sheet lapped over two lines of studs at joints or otherwise effectively sealed at joints. Because the polyethylene sheet has some resistance to air flow, it must be supported over its entire surface area.[6] Placement of the polyethylene between interior gypsum board and batt insulation is the currently accepted method. However, if air does leak through the interior drywall, some compression of the batt insulation may occur which, in turn, may produce a gap for convection in the future.
- The interior sheathing may itself form the vapour barrier. Taped joints in the gypsum board and use of either two coatings of quality latex paint or vinyl wallpaper will be adequate for most residential interior environment conditions. Sealants should be used to reduce air flow around the wall or openings in the wall, even if this is not the location of the air barrier.

Where rigid insulation is used on the outside of the backup wall, this insulation may itself provide an effective vapour barrier. However, with 90-mm thick batt insulation in the cavity, the dewpoint will normally lie within the batt insulation unless an uncommonly large thickness of rigid insulation is incorporated into the design. In lieu of more accurate calculations, a rule of thumb is that two-thirds of the thermal resistance should lie outside of the vapour barrier. Otherwise condensation of moisture will occur at the inside of the rigid insulation which could lead to:

- wetting of the batt insulation which in the short term reduces its thermal resistance value and in the long term may cause it to become compressed;
- accumulation of frost and water on the inside of the rigid insulation or exterior gypsum board. This water may run down into the track where it promotes corrosion of the track and anchors, or the gypsum board may be softened to the extent that it no longer serves its original functions; and
- in extreme conditions, mildew and mold can form which has health implications as well as durability effects.



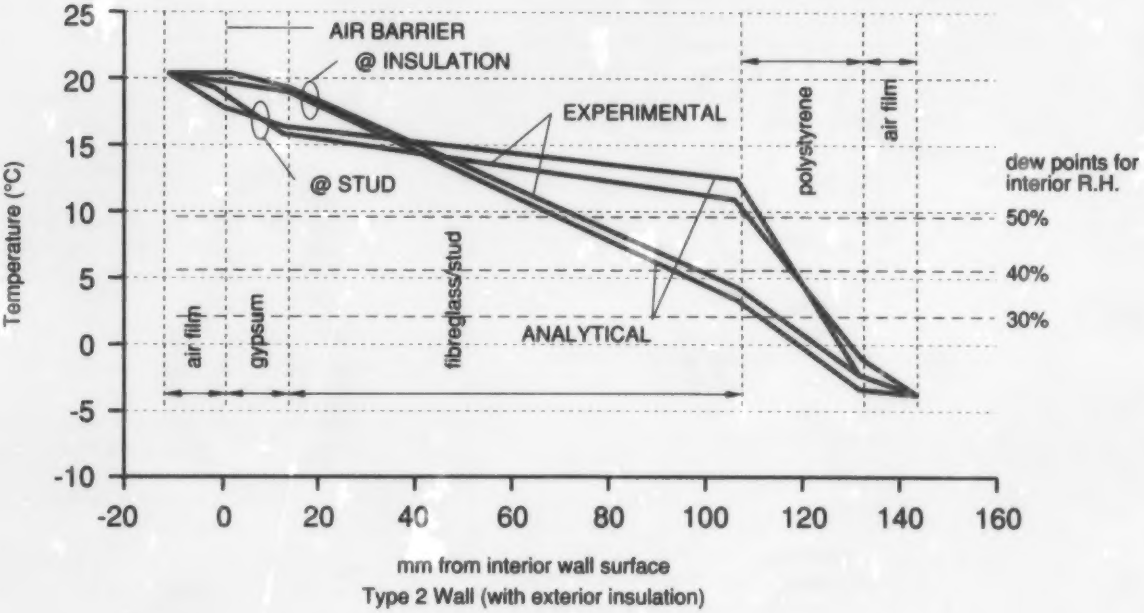


Figure 10.3 Thermal profiles along the stud-line and through the inter-stud space for walls with and without exterior insulation

## *10.5 RESISTANCE TO AIR FLOW*

As an extension to the discussion of air barriers in Section 8.9, sound positive and negative arguments can be made for locating the air barrier either on the inside or on the outside of the SS wall assembly. Again, it is suggested that an assessment of the vulnerabilities for particular situations may help in making the decision (see Figure 10.4).

### *GYPSUM BOARD AS INTERIOR AIR BARRIER*

If the gypsum board on the interior of the SS assembly is used as the principal air barrier, it has the following positive aspects:

- The air barrier and all its components are maintained at warm room temperatures and therefore may be less susceptible to opening of cracks due to thermal movement or embrittlement of sealants. In addition, the air barrier is above the dewpoint and therefore less susceptible to moisture attacks.
- The air barrier is relatively easy to inspect and faults can be corrected at almost any stage of construction since the barrier is not covered over with subsequent layers of construction.
- Similar to the points above, maintenance or repair may be readily carried out on the interior wall covering. This includes replacement of caulking where it is used as part of the air barrier.
- Continuity of the air barrier with window frames and other through-the-wall openings may be more easily accomplished where flashings above and below the window make it difficult to achieve a permanent seal at the outside of the SS backup wall.

The following are the main negative factors:

- Occupant use, such as hanging pictures and drapery track, may puncture the air barrier.
- Installation of such services as electricity may provide large, difficult to seal punctures (e.g., outlets) through the air barrier.
- Movement joints, particularly at the track which allows for vertical movement, may be difficult to seal because aesthetics may limit the use of effective materials or construction techniques.

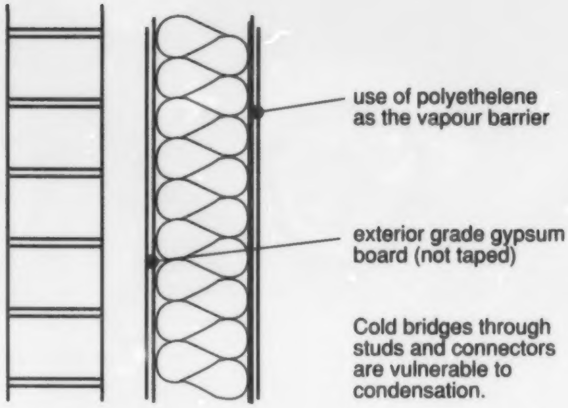
### *SHEATHING AS EXTERIOR AIR BARRIER*

If the exterior sheathing is used as the air barrier, it has the following advantages:

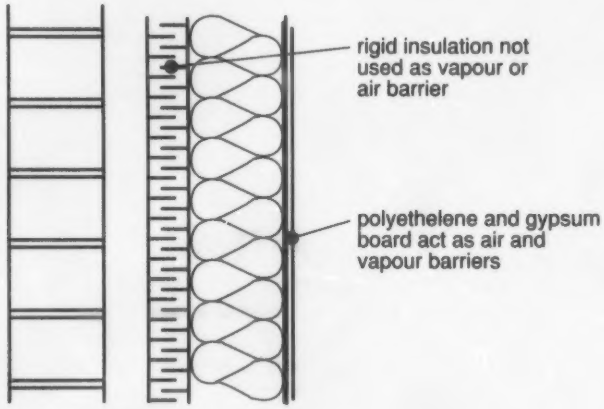
- When completed, the air barrier is unlikely to be damaged by subsequent building trades or by occupants.
- Use can be made of newly developed materials such as stick-on, torch-on, or spray-on sheets as strips to seal joints between the exterior sheathing and between the exterior sheathing and the surrounding structure.

The disadvantages are the following:

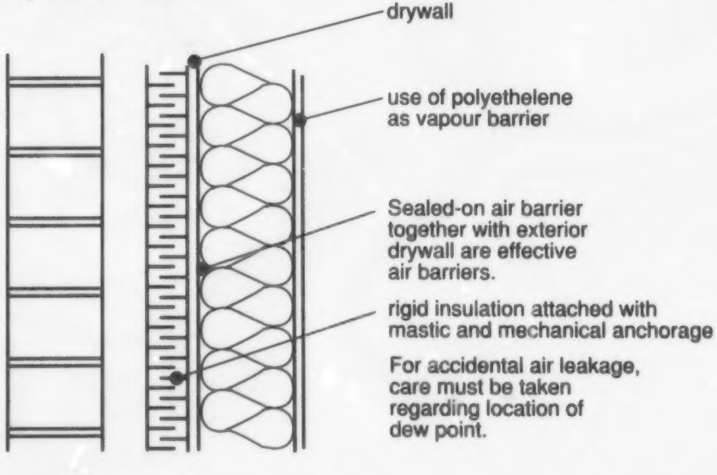
- The construction is not conveniently inspected and unless full-time inspection is undertaken or construction is delayed until inspections have been completed, significant parts of the air barrier are likely to be covered up before adequate inspection.
- Long-term maintenance and repair of deteriorated areas or faults is virtually impossible. Therefore high-quality construction must be guaranteed and materials must have excellent long-term performance characteristics.
- Ties, screws, and other wall fixtures may be very difficult to seal.


use of polyethelene
as the vapour barrier
exterior grade gypsum
board (not taped)
Cold bridges through
studs and connectors
are vulnerable to
condensation.

a) Insulation only in stud cavity


rigid insulation not
used as vapour or
air barrier
polyethelene and gypsum
board act as air and
vapour barriers

b) Exterior insulation


drywall
use of polyethelene
as vapour barrier
Sealed-on air barrier
together with exterior
drywall are effective
air barriers.
rigid insulation attached with
mastic and mechanical anchorage
For accidental air leakage,
care must be taken
regarding location of
dew point.

c) Exterior insulation and air barrier

Figure 10.4 Various locations of vapour barriers and air barriers for the SS wall system

As illustrated in Figure 10.5, to create an effective air barrier it is important to detail effective and constructible methods of handling continuity of the air barrier at:

- bottom track;
- movement joints (principally at the top of the backup wall for vertical movement);
- windows and other openings;
- connections to partitions and other parts of the structure; and
- locations where the barrier is punctured by services or other attachments.

## 10.6 INTERIOR WALL COVERING

For residential construction, gypsum board interior sheathing is the main type of material used because of fire protection qualities, cost, ease of application, and overall suitability for interior finishes. With taped and filled joints and corners, the flat wall surface is suitable for painting, wallpapering, or installation of decorative panelling, tile, fabric, or built-in cupboards.

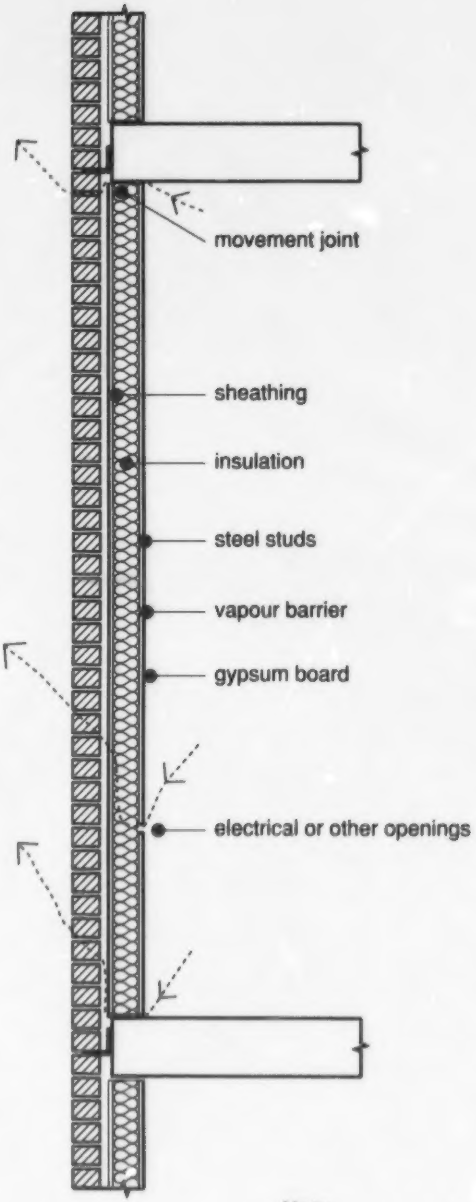
The principal weakness of the gypsum board covering is that it cannot tolerate wetting.

## 10.7 LOCATION OF WALL COMPONENTS

From a theoretical point of view, it is well established that the vapour barrier must be located on the warm side of the insulation or, where several layers of insulation are used, it must be positioned in-board of the depth representing the dewpoint location. Similarly, it is known that insulation on the outside of the backup wall is most effective since it helps keep the components of the backup wall warm. Minimizing thermal deformations, prevention of condensation, and moderate temperatures should all aid in maintaining the integrity of the air and vapour barriers.

Because the steel components of the backup wall are zones of thermal bridging, it is important that a strategy be adopted to minimize this effect.

While placement of insulation on the inside of the steel backup wall is feasible, it will result in the steel stud being much colder and therefore more prone to condensation of airborne moisture. Figure 10.6 (a) illustrates the temperature distribution at the interior face of exterior sheathing for various configurations of thermal insulation. The dewpoint temperatures for air exfiltrating from humidified buildings are also shown for interior air at 20°C and 30, 40, and 50 percent relative humidities. In Figure 10.6(a), the three graphs represent temperature ranges from 20°C on the inside to -10°C, -20°C and -30°C respectively. The five cases in each graph represent thickness of exterior insulation from 0 to 100 mm. Since there is batt insulation in the stud cavity, the temperature on the interior of the sheathing is below the dew point for many of the situations shown. However, because of its exposure to the warm interior, the steel stud can be adequately insulated to remain above the dew point of exfiltrating air.



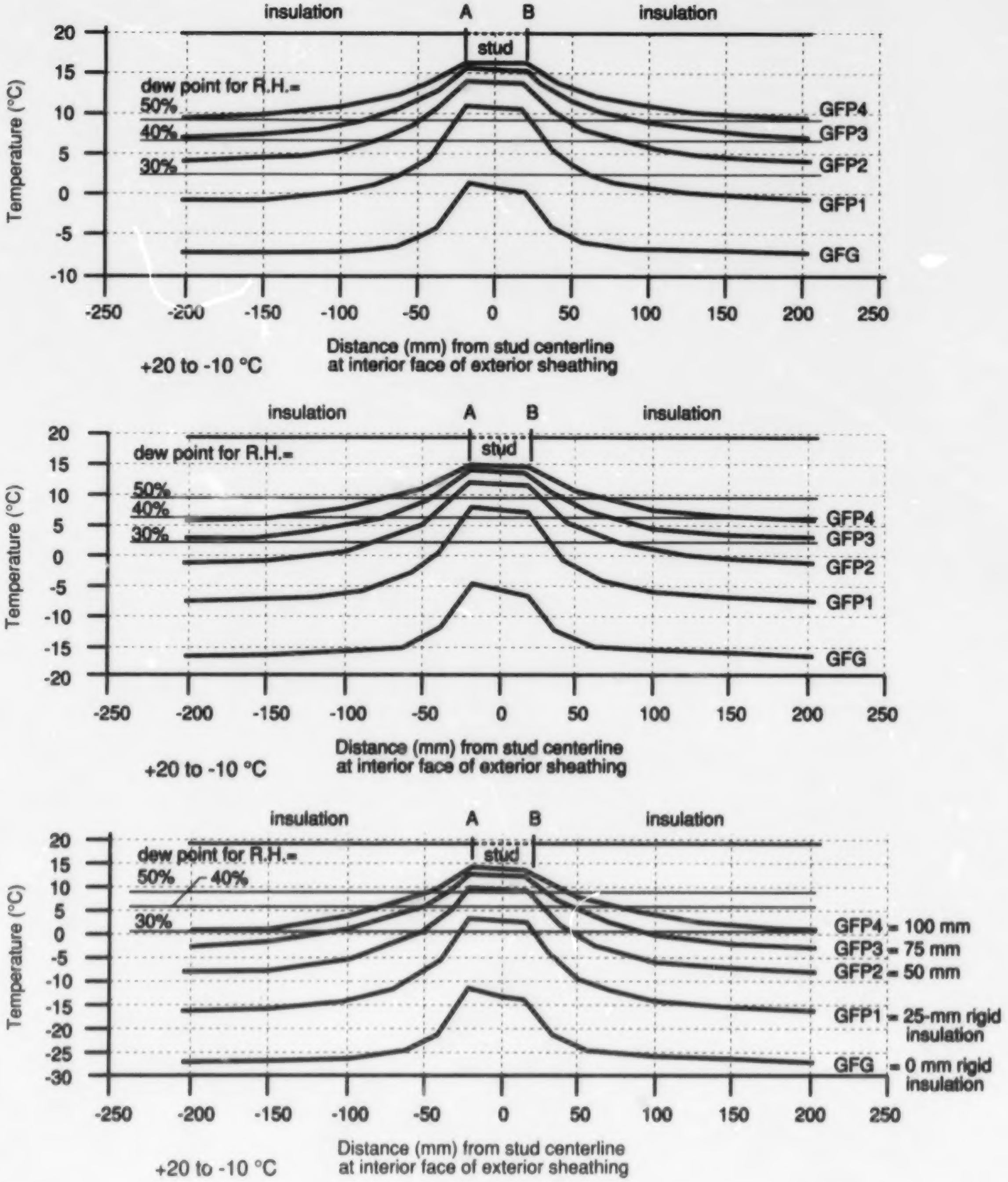
Steel stud backup walls present the same problem as other wall constructions in obtaining a good air seal at all junctions and fixtures.

It may be especially difficult to devise a good detail below the ceiling slab since a movement gap should be left at the top of the studs to prevent buckling under floor slab deflections.

movement joint
sheathing
insulation
steel studs
vapour barrier
gypsum board
electrical or other openings

Note:
Seal leakage paths are shown.

Figure 10.5 Typical air leakage paths for BV/SS construction



Note: The exterior sheathing is either gypsum board (G) or polystyrene (P). All results are for walls constructed with 12.5-mm of gypsum board on 92-mm 20-ga. studs filled with fibreglass batt insulation (F).

Figure 10.6 (a) Temperature distribution at the inside face of exterior sheathing for different thicknesses of exterior rigid insulation

In Figure 10.6(b), various types of insulation configurations are compared. Use of only exterior insulation provides the wall least susceptible to condensation, whereas the more traditional stud cavity insulated walls or a wall with an interior layer of insulation are most vulnerable to condensation of moisture from exfiltrating warm air. In these latter cases, having a very effective air barrier is essential to avoid the detrimental effects of condensation.

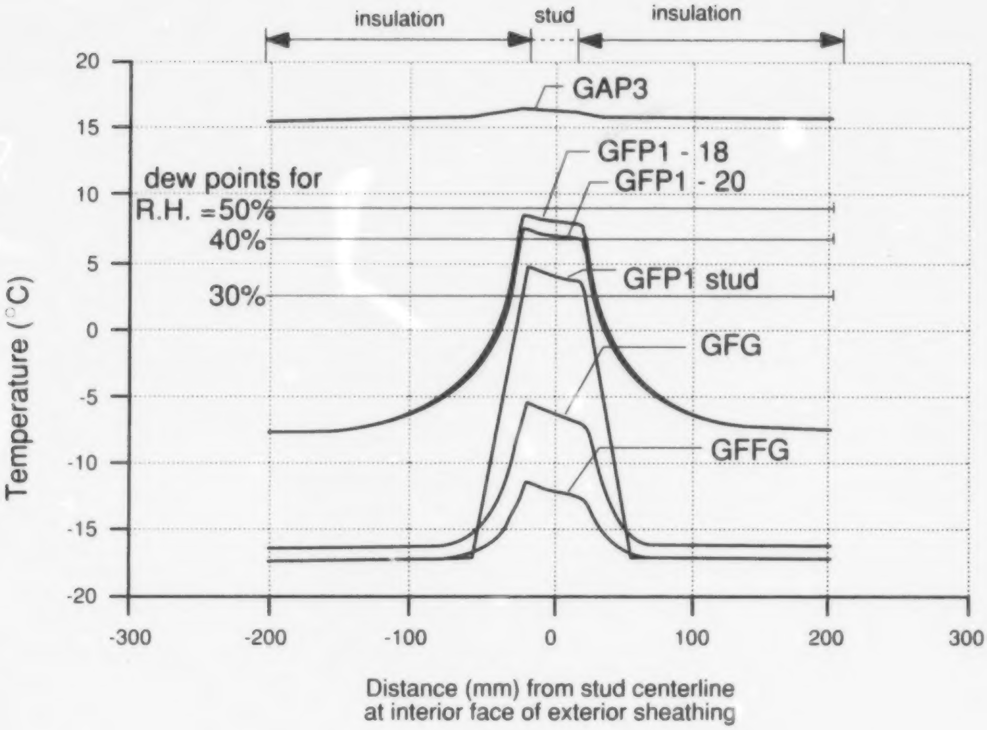
If it is assumed that some exfiltration of moisture-laden air will occur, then it seems reasonable to choose insulation and insulation locations which will minimize condensation, particularly on critical components. In addition, for cases where condensation in the wall does occur, the potential for the wall to dry out should also be assessed.[7]

As was discussed in Sections 8.9 and 8.13, the decision on the location of the air barrier should be influenced by practical considerations such as inspection requirements, repairability, long-term durability and maintenance. Therefore, location of the air barrier at either the outside or inside surfaces of the SS backup wall may be appropriate for particular situations.

## *10.8 VULNERABILITIES*

It was recommended that every design should be subjected to a *vulnerability assessment* before final adoption. In addition to the general categories to be assessed as outlined in Section 8.12, the vulnerability factors unique to the use of SS construction are:

- likelihood of cracking of the veneer and the influence of potentially greater leakage on performance of the wall;
- construction conditions and the effectiveness of quality control to produce a near-perfect air barrier (The air barrier must be designed to be continuous and movement joints must be effectively spanned by extensions to both air barrier and vapour barrier. The choice of BV/SS air barrier components must be tied to the level and frequency of inspections required to achieve satisfactory performance.);
- long-term durability and ability to carry out regular maintenance;
- support for vapour barrier if it is a separate component from interior sheathing;
- the air barrier/vapour barrier design should be evaluated as a potential double-barrier system where air leakage may occur; and
- design and construction provisions must ensure that moisture due to exfiltration or infiltration does not expose metal components to repeated wetting and potential corrosion.



GAP3 = wall with no insulation in the inter-stud space and 75-mm rigid insulation on the outside.

GFP1-18 and GFP1-20 = wall with fiberglass in the inter-stud space and 25-mm polystyrene exterior sheathing. 18- and 20-gauge studs were used.

GFP1 stud refers to the case where rigid insulation was just put over the exterior flange of the stud.

GFG is the gypsum board covered wall with no exterior insulation.

GFFG is the standard wall but with a 25 mm layer of fibreglass on the interior face of the stud.

Figure 10.6(b) Temperature profiles for various wall configurations

## *10.9 KEY CONSTRUCTION REQUIREMENTS*

From previous discussions of BV/SS building science requirements and other considerations, the following key construction requirements for construction of the system stand out:

- The quality of the veneer construction including filling and tooling of joints is of great importance to achieve a sound first barrier against rain penetration.
- Flashing must be securely and continuously attached to the backup in order to intercept water and direct it out of the cavity.
- In addition to proper installation of air and vapour barriers over the wall surface, continuation of these barriers at upper and lower tracks, windows and ends of walls requires special attention to prevent damage due to build-up of condensation and ice.
- Batt insulation in the inter-stud cavity must fit snugly to eliminate air circulation or sagging of the insulation.
- Spaces between double studs or other stud wall assemblies must be filled with insulation during construction to minimize the effects of thermal bridging.
- Work by various trades must be co-ordinated to prevent damage to completed work.
- The minimum acceptable level of galvanizing should be G90.

## REFERENCES

[1] Drysdale, R. G., and Wilson, M. J., *A Report on Lateral Load and Rain Penetration Tests of Full Scale Brick Veneer/Steel Stud Walls*, Report submitted to the Project Implementation Division, CMHC, Ottawa, July 1990.

[2] Drysdale, R. G., and Kluge, A., *A Report on Performance of Brick Veneer/Steel Stud Wall Systems Subject to Temperature, Air Pressure, and Vapour Pressure Differentials*, Report submitted to the Project Implementation Division, CMHC, Ottawa, June 1990.

[3] Sasaki, J.R., *Thermal Performance of Exterior Steel-Stud Frame Walls*, NRCC Publication No. 2226, PBR, 1972.

[4] Drysdale, R. G., and Chidiac, S., *Defining Better Wall Systems*, Report submitted to the Research Division, Canada Mortgage and Housing Corporation, Ottawa, May 1989.

[5] Drysdale, R. G., and Kluge, A., *A Report on Performance of Brick Veneer/Steel Stud Wall Systems Subject to Temperature, Air Pressure, and Vapour Pressure Differentials*, Report submitted to the Project Implementation Division, CMHC, Ottawa, June 1990.

[6] Shaw, C. Y., *Air Leakage Tests on Polyethylene Membrane Installed in a Wood Frame Wall*, Building Research Note 225, DBR, NRC, Ottawa, January 1985, 25 pages.

[7] Rousseau, M. Z., *Control of Surface Concealed Condensation*, Building Science Insight 83, DBR/NRCC, May 1984.

# PART 4 SPECIAL TOPICS

## CHAPTER 11

## PARAPET AND ROOF CONNECTIONS

### 11.1 INTRODUCTION

Parapets are one of the most exposed parts of a building, being subject to wind-driven rain and temperature extremes on both wall faces. Water penetrating parapets and draining into walls below has been responsible for moisture problems. Their proper flashing has been discussed professionally for many years. A variety of materials are used, and there is no standard parapet design. Some designers prefer to omit parapets whenever possible and simply use well-flashed curbs at roof edges.

### 11.2 DETAILS

CSA Standard CAN3-A371-M84 stipulates that parapets be constructed of solid or grout-filled hollow units.[1] Parapets are also required to have through-the-wall flashings and, if they are less than 300 mm thick, to be flashed on the back for their full height, or at least 900 mm above the roof level. This is to take care of the likelihood of snow drifting against the parapet. Figure 11.1(a) shows such a parapet. For parapets not more than one block in height above the roof level, grouting of the cavity and separate support of the veneer may not be required.

As an alternative to constructing a solid parapet to prevent entry of moisture, an insulated parapet such as shown in Figure 11.1(b) can be used. Insulating the faces and top of the backup wall part of the parapet reduces heat loss and interior cold spots caused by thermal bridging. The continuous insulation will result in reduced deformation of the backup and improved air barrier performance and long-term durability of the assembly.

Instead of a parapet, many high-rise residential buildings today use a metal cap as illustrated in Figure 11.2. Simple to construct, such a detail can achieve a satisfactory continuity of the building envelope between veneer and roof.

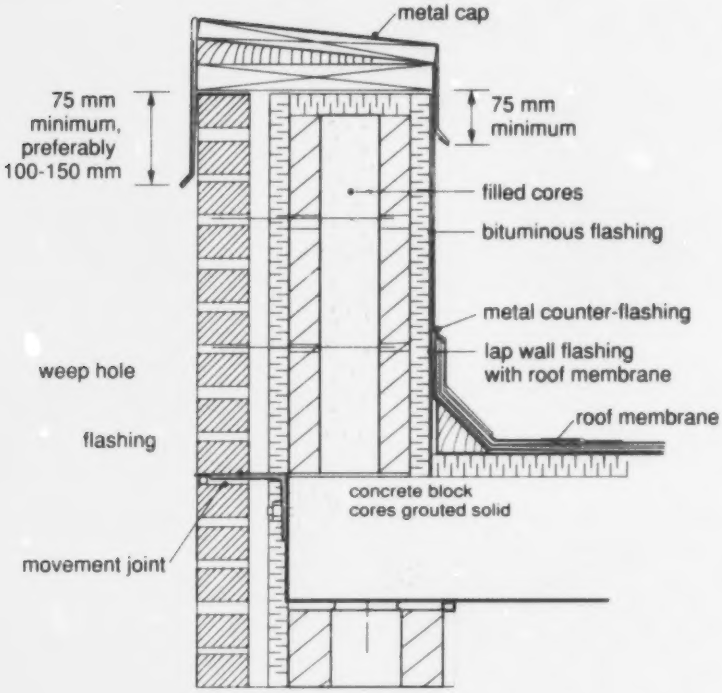
Key construction recommendations:

For veneer, provide mortar-free movement joint.

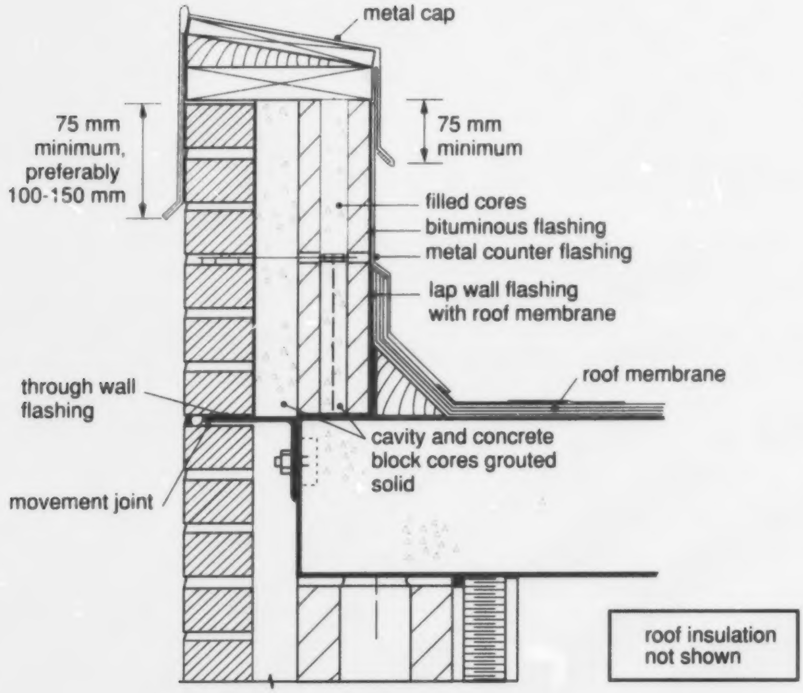
Install flashings and counter flashings with great care since parapet is typically the most exposed building element.

Achieve complete continuity between roof membrane and flashing.

An alternative to grouting the cavity is to insulate the backup wall on both faces and the top.

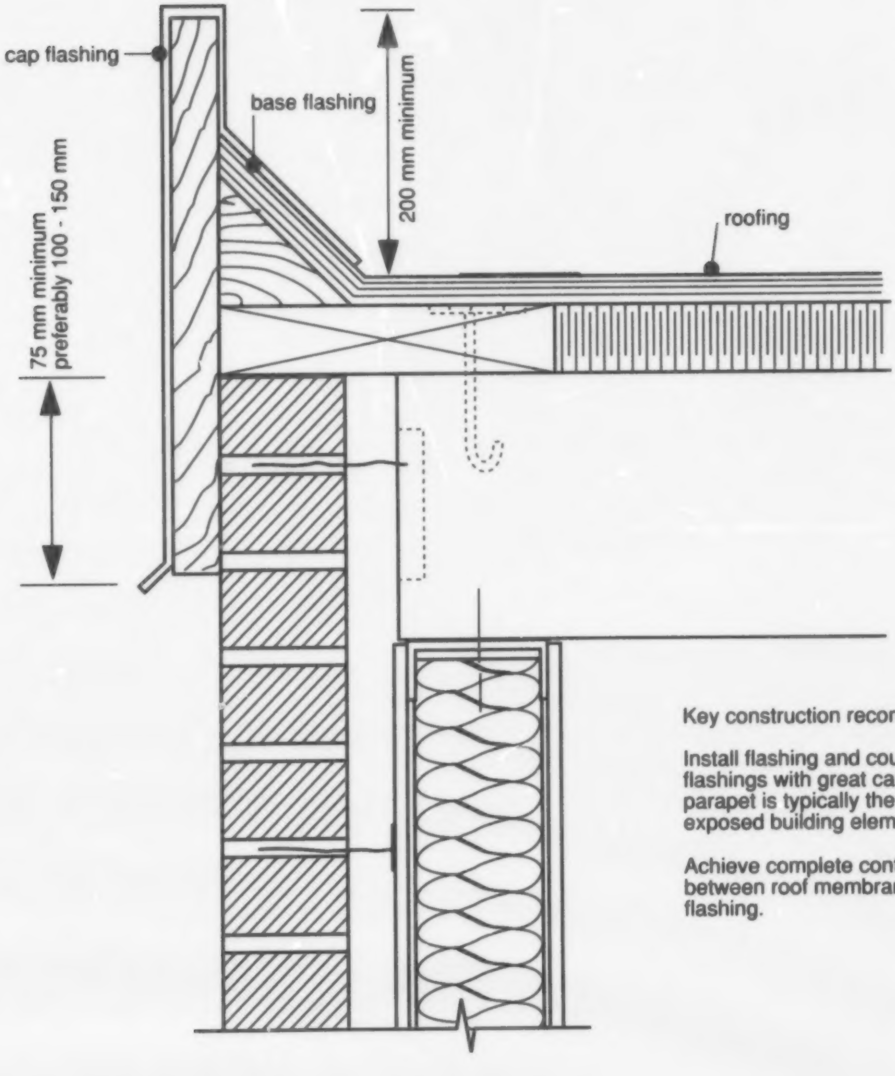

metal cap
75 mm minimum, preferably 100-150 mm
75 mm minimum
filled cores
bituminous flashing
metal counter-flashing
lap wall flashing with roof membrane
weep hole
roof membrane
flashing
concrete block cores grouted solid
movement joint

a) Insulated


metal cap
75 mm minimum, preferably 100-150 mm
75 mm minimum
filled cores
bituminous flashing
metal counter flashing
lap wall flashing with roof membrane
roof membrane
through wall flashing
cavity and concrete block cores grouted solid
movement joint
roof insulation not shown

b) Solid grouted

Figure 11.1 Parapet flashing


cap flashing
base flashing
200 mm minimum
roofing
75 mm minimum
preferably 100 - 150 mm

Key construction recommendations:

Install flashing and counter-flashings with great care since parapet is typically the most exposed building element.

Achieve complete continuity between roof membrane and flashing.

Figure 11.2 Flashed curb

## REFERENCE

[1] Canadian Standards Association, CAN3-A371-M84, *Masonry Construction for Buildings*, CSA, Rexdale, 1984, 50 pages.

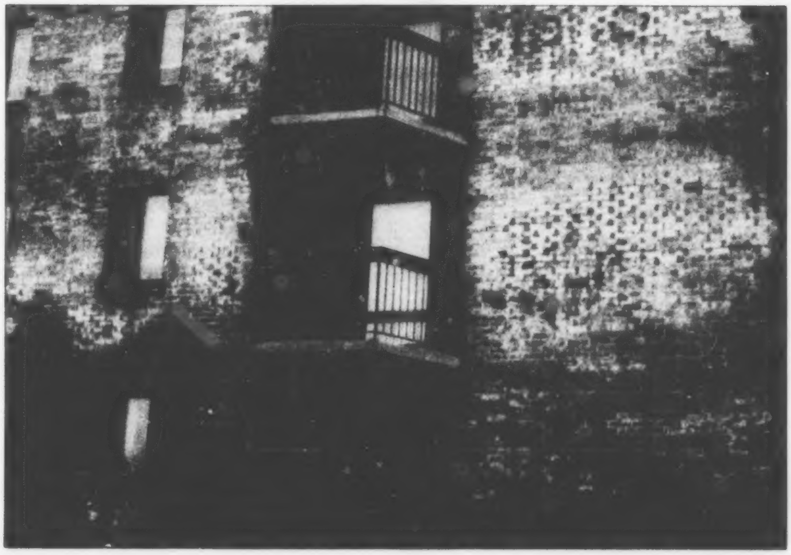
# CHAPTER 12

# EFFLORESCENCE

## 12.1 INTRODUCTION

Many kinds of water-soluble salts are present in mortar and masonry units. Where contrary to good practice, masonry is in direct contact with soil or a dampproofing course is omitted, such salts can also be carried into the masonry by moisture originating from the soil. As moisture in the wall reaches the exterior and evaporates, the water-soluble salts crystallize and may form a usually whitish deposit on the exterior of the masonry. The effect is termed efflorescence.

Especially for cases of relatively severe efflorescence as shown in Figures 12.1 and 12.2, the disfiguring staining may affect property and rental values and hence is annoying to owners. For efflorescence to occur, both water soluble salts and moisture must be present. The following sections will deal with sources of salts, sources of moisture, and measures for prevention and control of efflorescence. Other sources give a more comprehensive treatment of topics about efflorescence.[1,2,3]

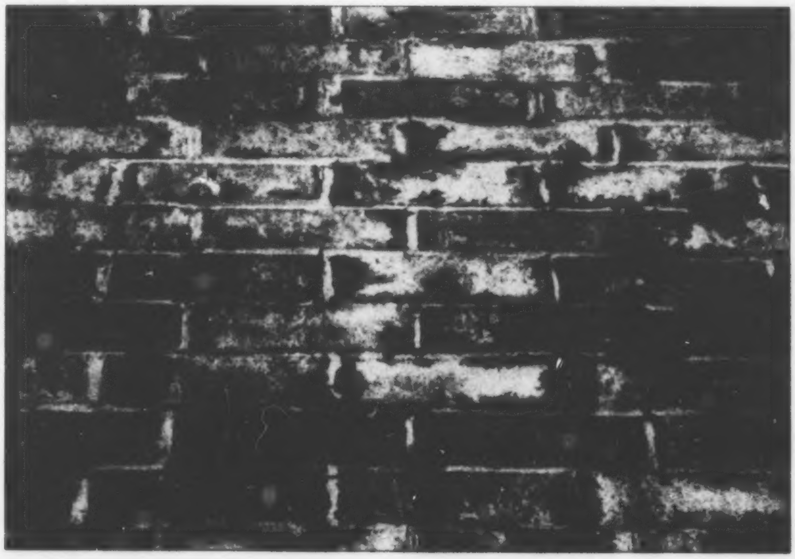


▼ *Figure 12.1 Widespread efflorescence on the brick veneer denotes excessive moisture migration due to exfiltrating moist air, water infiltration or a combination of the two effects*

## 12.2 SOURCES OF SALTS

There can be many sources of salts, including brick units of the veneer, CM backup units, mortar, building trim, groundwater, and atmospheric pollutants. Typically for a veneer, the main sources are the mortar and the brick units.

Regarding mortar as a source of efflorescence, suction between freshly laid units and the plastic mortar will transfer soluble salts present in the mortar to the brick. The salts may be present in the mortar from the cement, the sand, or from calcium chloride added to the water used for mixing.



▼ *Figure 12.2 Close-up view of salt deposits from efflorescence*

Sodium and potassium hydroxides commonly present in Portland cements may cause some measure of efflorescence in newly laid masonry during the first year. This efflorescence is known as *new-building bloom* and the veneer is said to be *blooming* Studies have shown that increasing the amount of Portland cement in mortar increases the amount of efflorescence. Yet a given mortar showing pronounced efflorescence with one brick may not with another, and efflorescence is related as well, therefore, to the absorption rate of the masonry units. Presence of lime in mortar decreases the likelihood of efflorescence.

Since cavity wall construction invariably involves connectors which may corrode due to the presence of calcium chloride, the use of calcium chloride in mixing water should not be permitted. This then also eliminates such salts as a potential source of efflorescence.

Both clay brick and concrete brick may contain soluble salts which can be brought to the masonry surface as migrating moisture evaporates. A standard test is available to determine the capacity of the brick to contribute to efflorescence.[4]

Although soluble salts may also be present in concrete masonry used as backup, the presence of a cavity will interrupt the direct migration of salts to the veneer. The CM backup therefore should not be a significant contributor to efflorescence. On the other hand, building trim made of precast concrete, natural stone, or cast stone may contribute significantly to efflorescence of adjoining veneer. Such materials may contain considerable amounts of soluble salts which can be leached out over long periods of time.

## *12.3 SOURCES OF MOISTURE*

As newly constructed masonry dries out, blooming may be displayed for a few weeks or perhaps several months. Typically rains will remove this efflorescence and in a season or two the blooming effect will have disappeared. However, where efflorescence persists, a source of moisture should be looked for and controlled.

Rains, and particularly driving rains, can deposit substantial amounts of moisture in masonry walls. During periods of warmer weather, the rate of evaporation of moisture within a wall is relatively high, and soluble salts are therefore deposited within the brick veneer rather than on the surface. However, during colder weather, the rate of evaporation is slower and moisture-containing soluble salts can migrate to the surface of the veneer before evaporation. Hence, in the Canadian climate, late fall, winter and early spring represent the main seasons for recurring efflorescence problems.

Besides rain water, another major source of moisture can be leakage of moisture-laden air from the interior of a building. Discontinuities in air and vapour barriers will permit such moisture-laden air to exfiltrate and condense on wall components during colder weather. Such moisture can then migrate by capillary action and deposit soluble salts on the surface of the veneer.

## *12.4 PREVENTION*

Since soluble salts in various concentrations are present in many materials used in masonry construction and also since moisture must be present to cause efflorescence, for new construction it is important that aspects of material selection, design, construction, and maintenance are carried out with care to minimize the likelihood of efflorescence occurring on a building.

Concerning selection of materials, tests can establish that brick units do not effloresce and that mortars do not contain high solutions of water-soluble alkali. Use of mortar admixtures is generally not recommended because of their unknown ingredients and possible effect on masonry bond and on efflorescence.

Designs using cavity wall construction and the open rain screen principle is good practice because moisture penetrating the thin veneer can be vented and direct migration of salt solutions from CM backup is interrupted. Most important are design details which prevent the entrance of moisture into the wall system and direct accumulated water away from wall tops and other wall surfaces.

Critical details include air and vapour barriers (see Chapter 8), copings, caps, sills, flashing, drips, vents, and weep holes. Also critical are joints that are to be caulked, such as movement joints, and joints that are to be sealed, such as joints at window and door openings.

Construction must employ:

- good workmanship practices to achieve the measure of efflorescence control intended in the design;
- protection of the tops of walls under construction to control ingress of moisture; and
- proper storage of materials to ensure that moisture from rain and snow is kept away and contamination from salts is prevented.

Regarding maintenance measures to prevent efflorescence, the building envelope should be inspected periodically to spot moisture paths due to the deterioration of materials. Of critical importance is the proper maintenance of caulked joints and sealants.

## 12.5 CONTROL

*New-building bloom* will often disappear as repeated rainfalls rinse the soluble salts off the masonry surface. Where blooming persists or removal is required before natural weathering could do its work, rinsing with water while scrubbing with a brush is commonly employed. To help dissolve the salts, dilute solutions of hydrochloric acid are sometimes used. Two important points should be kept in mind when planning this type of efflorescence removal.

- The work should be carried out during periods of warm weather, so that the moisture absorbed by the masonry during the flushing operation can evaporate quickly and does not bring additional salts to the surface.
- Treatments involving even dilute solutions of acid must incorporate flushing with water both before and after application of the acid solution. This will minimize the retention of acid within the veneer where it could lead to corrosion of embedded steel.

Where efflorescence is caused by abnormal wetting of the wall as from poorly located drains and scuppers, missing drips and coping or deteriorated caulking, these faults must be rectified to control efflorescence. Particularly difficult and expensive to remedy is efflorescence caused by exfiltrating air escaping through weaknesses in the air and vapour barrier systems. A careful assessment of design details and as-built conditions especially around openings is usually required before remedial actions can be formulated.

A number of surface treatments are available commercially to help control efflorescence. In essence, these treatments typically impart various degrees of water repellency to the extreme outer layer of the masonry. While formation of efflorescence on the outer surface is suppressed partly because of less moisture entering the wall and partly because of evaporation of soluble salts taking place just behind the treated surface layer, serious problems may arise nevertheless. As the salts crystallize and accumulate behind the treated surface layer, pressures can be built up which lead to spalling of the masonry. Such surface treatments, however, can be successful, if they are carried out in conjunction with other measures which will control the amount of moisture entering the masonry veneer.

Use of surface coatings may also affect the freeze-thaw performance of veneers (see Section 14.4).

## REFERENCES

[1] Brick Institute of America, *Efflorescence, Causes and Mechanisms*, Technical Notes on Brick Construction, No. 23, May 1985.

[2] Brick Institute of America, *Efflorescence, Prevention and Control*, Technical Notes on Brick Construction, No. 23A, June 1985.

[3] Ritchie, T., *Efflorescence*, Canadian Building Digest No. 2, Division of Building Research, National Research Council, Ottawa, February 1960.

[4] Canadian Sheet Steel Building Institute, *Lightweight Steel Framing Manual*, CSSBI 50M-1987, August 1987, 23 pages.

[redacted]

# CHAPTER 13

# FREEZE-THAW RESISTANCE

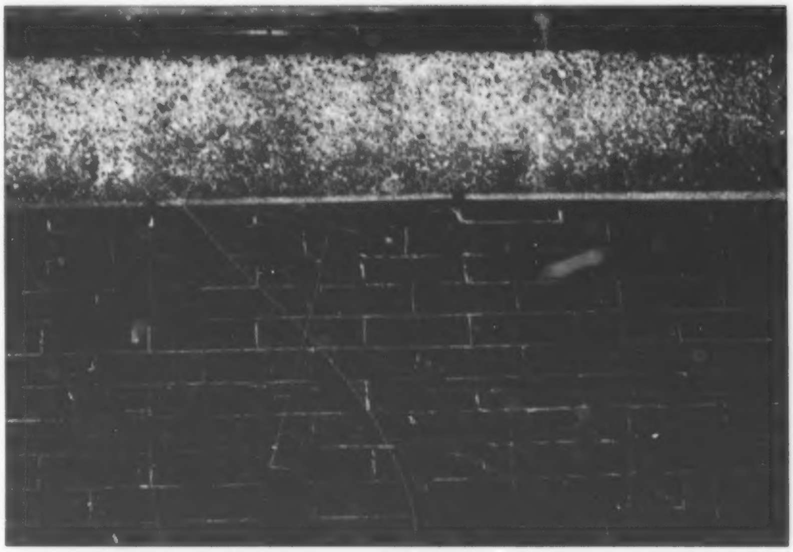
## 13.1 INTRODUCTION

Although one of the outstanding attributes of brick masonry is its durability, cases do occur where the freeze-thaw resistance of brick is inadequate to withstand the relatively harsh Canadian environmental conditions. Resultant brick spalling, as illustrated in Figures 13.1 and 13.2, is disfiguring and expensive to repair.

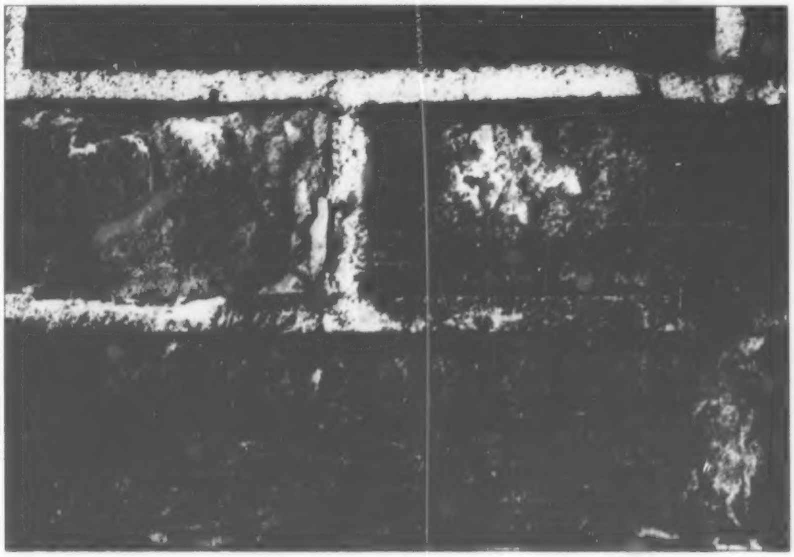
Freeze-thaw resistance is not a definite property of a porous material as compared to, say, strength or colour. Whether or not a brick fails during freeze-thaw depends on the pore structure, the rate of freezing, and the thickness of the material. It must be saturated to near the limit of its absorption capacity. Standard criteria such as strength, absorption, and saturation coefficient are known to be rather unreliable predictors; they accept as many as 20 percent of bricks that will fail the freeze-thaw test and reject about 30 percent of the resistant ones. Hard-fired clay bricks usually are relatively durable, but even a small difference in firing temperature can cause a change in freeze-thaw resistance.

Because glazed bricks have an exterior face which is virtually impervious, particular care in detailing and laying of such bricks is required to prevent eventual spalling problems due to freeze-thaw action. Moisture which may enter the glazed brick masonry at unfilled joints and hairline cracks can become trapped behind the impervious glazed surface; upon freezing, spalling may ensue. All too many spalling problems have been encountered in practice and their use on high-rise structures in many parts of Canada is therefore not recommended.

The following discussion is directed specifically at clay brick veneer because of its extensive use in high-rise applications and because concrete brick veneer is less susceptible to freeze-thaw durability problems.



▼ Figure 13.1 View of extensive spalling of frost susceptible clay brick



▼ Figure 13.2 Close-up view of clay brick spalling due to poor freeze-thaw durability

## 13.2 CODE CRITERIA

CSA Standard A82.1-M87[1] outlines grade of brick requirements according to a Canadian weathering index, which for any locality is the product of the average number of freezing cycle days and the average annual winter rainfall. In essence, the standard requires that a grade SW (severe weathering) brick be used for veneer construction across Canada.

For SW brick, the standard permits acceptance of brick, if the average saturation coefficient is less than 0.78, the average compressive strength exceeds 20.7 MPa, and the average maximum five-hour boiling-water absorption is less than 17 percent. It is noteworthy that the maximum value of 0.78 for the saturation coefficient is a new and considerably more stringent requirement than the value of 0.88 given in previous editions of the standard. While the change was made to affect a reduction of freeze-thaw brick failures in the field, the criteria of saturation coefficient, compressive strength, and absorption can only serve as indicators of later in-situ performance.

It should also be noted that the saturation coefficient and five-hour boiling-water absorption requirements may be waived provided the brick passes 50 cycles of freeze-thaw testing with no breakage and no weight loss exceeding 0.5 percent. Although the freeze-thaw test is regarded as a more reliable predictor of in-situ performance, it simply indicates if a brick wetted to a certain degree of saturation and frozen at a certain rate for an arbitrary number of cycles will fail or not fail. In-situ conditions may impose a much larger number of freeze-thaw cycles under differing climatic conditions which may be more severe than a standard freeze-thaw test.

## 13.3 RECENT RESEARCH

Besides the saturation coefficient, which is the ratio of the 24-hour cold-water absorption to the five-hour boiling-water absorption, recent research has indicated that specific surface area and pore structure have a significant influence on clay brick durability.[2,3,4]

A Division of Building Research (DBR) study of 27 bricks with known freeze-thaw field performance has indicated that some correlation exists between specific surface area and performance. From their work it is clear that underfired bricks would exhibit relatively large specific surface areas and consequently would be most prone to durability failures in the harsh Canadian climate.

A study of pore size distributions for brick indicates that pores can be classified coarse, intermediate, and small. Coarse pores (greater than 1 micron) enhance durability, for although they readily absorb water, they also dry out rapidly; intermediate pores (say, between 0.1 and 1 micron) are most prone to cause freeze-thaw damage because they dry out more slowly than coarse pores, yet are frequently saturated under service conditions; small pores do not fill or dry easily and freeze only at quite low temperatures, hence do not represent a major cause of freeze-thaw breakdown of a brick. The major cause is seen to be the intermediate pore and in particular the percent volume of such pores in relation to the other two sizes. If an assessment of total porosity shows a preponderance of intermediate pores, the brick will likely not be durable.

### 13.4 BEST PRACTICE

To minimize the potential for brick durability problems, heed the following recommendations:

- the performance record of a brick over at least five years under varying exposure conditions should be checked;
- the uptake of moisture in the brick should be controlled by careful detailing and workmanship as well as by regular maintenance measures; and
- brick in especially critical applications should be tested not only to meet the standard freeze-thaw durability requirements of CSA A82.1-M87 but also non-standard requirements of specific surface area and pore structure.

It should be noted that surface coatings applied to control moisture uptake in veneer may act to some degree as a vapour barrier trapping moisture in the brick, thereby creating conditions susceptible to freeze-thaw damage.

## REFERENCES

[1] Canadian Standards Association, CAN/CSA-A82.1-M87, *Burned Clay Brick (Solid Masonry Units Made from Clay or Shale)*, CSA, Rexdale, 1987, 17 pages.

[2] Crooks, R. W., Kilgour, C. E., and Winslow, D. N., *Pore Structure and Durability of Bricks*, Proceedings of Fourth Canadian Masonry Symposium, University of New Brunswick, June 1986.

[3] Kung, J. H., *Frost Durability of Clay Bricks – Evaluation Criteria and Quality Control, Proceedings No. 8*, Division of Building Research, National Research Council, NRCC 23294, April 1984.

[4] Robinson, G. C., The Relationship Between Pore Structure and Durability of Brick, *Ceramic Bulletin*, Vol. 63, No. 2, 1984, pp 295-300.

# CHAPTER 14

# SURFACE COATINGS

## 14.1 INTRODUCTION

The main reason for applying coatings to masonry surfaces is to help control moisture movement. Masonry coatings can be classified either as solvent-based or as water-based coatings. The former contain or are soluble in organic solvents, whereas the latter dissolve in or are dispersed in water. The successful performance of coatings depends on correctly assessing the cause of wall distress and then choosing the appropriate coating material both for the distress at hand and the masonry material properties.

The choice of coating and whether or not a coating is appropriate will also be very much influenced by climatic and environmental conditions, that is, a type of coating with a well proven performance record in temperate regions of British Columbia may not be suitable in northern regions.

## 14.2 MASONRY MATERIAL PROPERTIES

In applying coatings to masonry, masonry material properties such as porosity, surface roughness, alkalinity, and the presence of soluble salts are of key importance.

**Porosity.** While clay brick is porous to small water molecules, coatings generally contain much larger molecules. Therefore, some denser bricks are relatively non-porous to coatings.

**Surface Roughness.** Since the chemical constitutions of the masonry substrate and coatings differ markedly, little chemical bonding takes place and adhesion depends mainly on mechanical keying. Most clay bricks exhibit considerable surface roughness for good adhesion; glazed bricks are an exception.

**Alkalinity.** The main coating problem caused by alkalinity in the masonry has been a chemical reaction between oil-based coatings and alkali, called saponification. Unless non-saponifiable coatings are used, a coating film can become soft and tacky. Clay brick normally being neutral, alkalinity in the veneer would be furnished by the mortar.

**Soluble Salts.** As discussed in Chapter 12, soluble salts may cause efflorescence. Efflorescence, in turn, may cause coating failure by mechanically destroying the film, the force exerted during crystallization of the salts strong enough to overcome the bond to the substrate. Where efflorescence is encountered, it is important to remedy the source of moisture and not rely on a coating to perform a miracle function for which it is not designed.

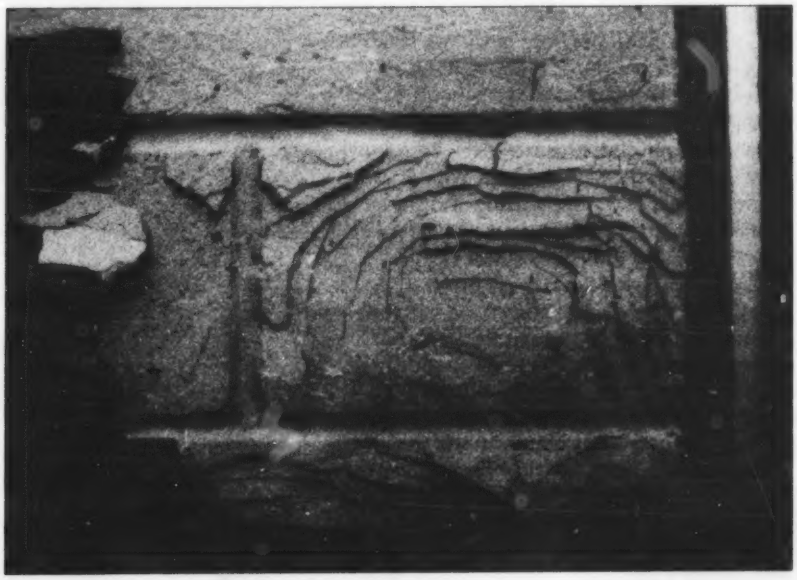
## 14.3 TYPES OF COATINGS

A large variety of both solvent- and water-based coating materials are available. Too numerous to list here in detail, they include latex paints, "breathing type" heavily applied coatings and silicones.

**Latex Paints.** Water-based latex paints, exhibiting a high water vapour permeability, have performed well on masonry surfaces. Repainting should be carried out prior to excessive chalking since otherwise poor adhesion could ensue.

*Breathing type*, **Heavily Applied Coatings.** These have been used extensively because they can hide such minor imperfections as hairline cracks, and their water vapour permeability, although normally relatively low, does allow some minor amounts of moisture in the masonry to be vented. They can be either solvent- or water-based and typically contain a large amount of pigment mixed with a low amount of binder. Since adhesion is mostly mechanical, good surface roughness is required for a good bond.

▼ Figure 14.1 Coating failure due to excessive moisture buildup behind the coating



▼ Figure 14.2 Failure of both the coating and the brick. The coating was originally applied to improve the marginal freeze-thaw durability of the brick

**Silicones.** For masonry applications two types of silicone have been developed: one solvent-based and the other water-based. Both alter the surface of the absorbent masonry so that it tends to repel water. The solvent-based silicone is a silicone resin which is typically applied to external wall surfaces. Penetrating the pores to some depth, the silicone remains after the solvent has evaporated. The water-based silicone is sodium methyl siliconate which is normally factory-applied to masonry units exhibiting abnormally high absorption rates. After application, the siliconate is converted to a water-insoluble resin with exposure to the carbon dioxide of the atmosphere.

## 14.4 BEST PRACTICE

Whenever coatings are considered for masonry surfaces, it should be clearly understood that coating failure will take place when large amounts of moisture are able to enter the masonry through defects, such as cracks or unfilled joints, poor detailing, or moisture-laden exfiltrating air. As this moisture builds up behind the coating, adhesive failure of the coating occurs. Even *breathing-type* coatings, including silicones, are not designed to handle the passage of larger quantities of moisture without distress. Under freeze-thaw conditions in particular, the highly saturated masonry may fail by delamination of the surface including the coating. Figures 14.1 and 14.2 illustrate coating failures.

Additional best practice recommendations are the following:

- Coating performance on similar masonry in the same geographic and environmental region as the intended project application should be checked.
- In applying coatings to masonry, it is important to closely follow manufacturer's instructions, otherwise coating performance may be seriously impaired.
- Since the service life of coatings depends on such factors as type of coating, type of substrate, geographic location, and exposure conditions, a periodic checkup of performance is good practice. Re-application of coatings is typically required at 5- to 10-year intervals.

Ashton[1] provides a comprehensive treatment of coating issues pertaining to masonry surfaces.

## REFERENCE

[1] Ashton, H. E., *Coatings for Masonry Surfaces*, Canadian Building Digest No. 131, Division of Building Research, National Research Council, Ottawa, November 1970.

# CHAPTER 15

# MAINTENANCE AND REPAIR

## 15.1 POST-CONSTRUCTION INSPECTIONS

All building materials deteriorate to some degree with time because of weathering, aging, and other environmental effects. Concerning durability of the BV/CM and BV/SS cladding systems, poorly maintained joints may, for instance, permit infiltration of excessive amounts of moisture. Since time of wetness is a key factor in controlling the rates of corrosion of steel, the frequent presence of excessive amounts of moisture may lead to premature corrosion distress in steel components of the cladding systems. Other cladding distress may be related to such material problems as unsatisfactory freeze-thaw-resistance of the brick; poor design detailing, such as absence of movement joints; or poor construction practices, such as inadequate attachment of a shelf angle.

Since most cladding problems only become apparent quite some time after completion of construction and also since initially minor problems may evolve major distress, potentially endangering the safety of the public, owners must recognize the need for periodic post-construction inspections of building enclosures.

From an economic point of view it also makes sense to carry out periodic maintenance and minor repairs rather than allowing deterioration to proceed until major repairs or replacement of the cladding system are required. Figures 15.1(a) and (b) illustrate this point schematically.

As shown in Figure 15.1(a), the soundness of a cladding system reduces with time, first very slowly but during later periods at an ever-increasing rate.

Assuming point B on the curve represents a degree of soundness which divides serviceability problems from safety problems, that is, at soundness levels above B a safety problem is not present, then it is clear that periodic maintenance/minor repair actions are required at a time before $t_B$. If such actions were taken at a degree of soundness shown as point A in Figure 15.1(a), the serviceability problems of the cladding system would be remedied so that at a time $t_A$ the system again achieves the 100 percent soundness similar to its original newly constructed condition. The deterioration cycle would then repeat itself until at some future date ($t_C$) further maintenance/minor repairs would be initiated.

Figure 15.1(b) indicates that maintenance/repair costs escalate significantly as the level of soundness of the cladding system decreases. In particular, the schematic curves show that very major costs are encountered once safety problems come into play and also that it is economically advantageous to commit maintenance/minor repair funds periodically rather than face much more major costs once the system has badly deteriorated.

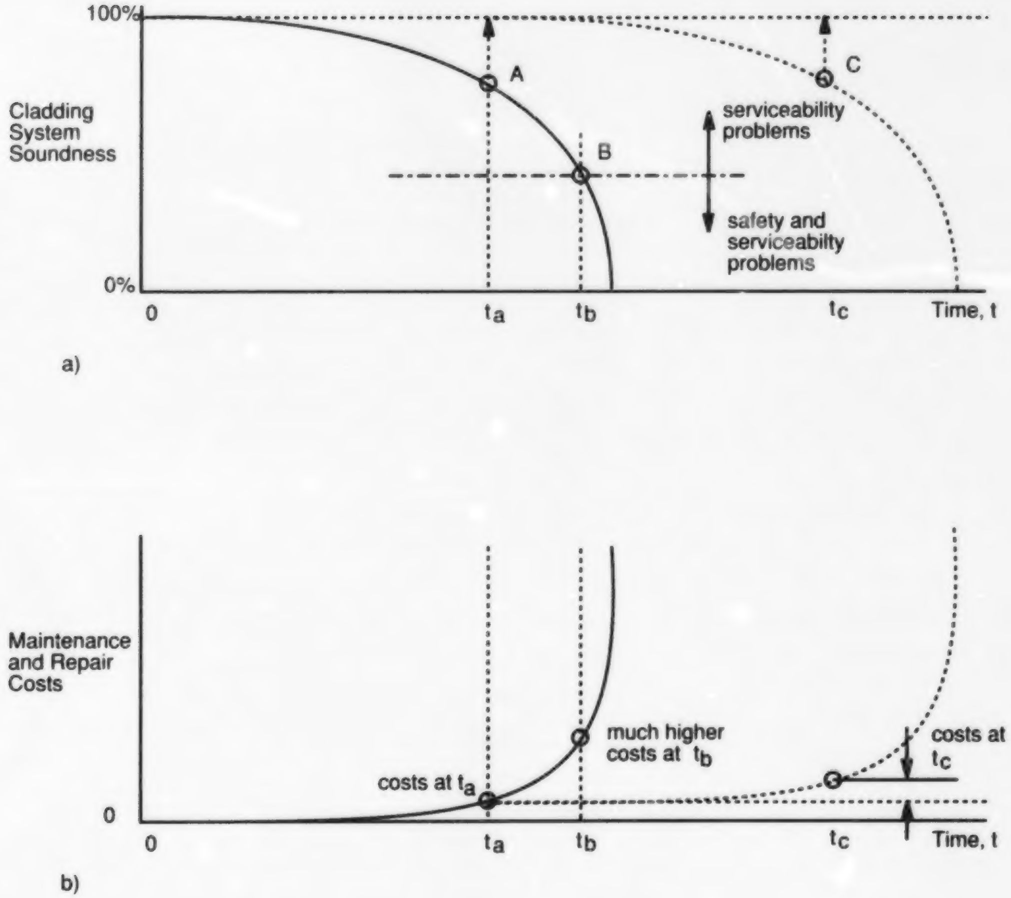


Figure 15.1 Schematic illustration of soundness and maintenance/repair costs versus time for a cladding system

## *15.2 FREQUENCY AND NATURE OF INSPECTIONS*

Periodic post-construction inspections should be carried out at 2- to 5-year intervals, depending on past experience in the climatic region of the country and past history of the cladding system on the particular structure. Such inspections should be conducted by a qualified professional whose trained eye and experience are invaluable in discerning what level of inspection is appropriate. While visual observations, including binocular scans of building envelopes, may suffice for some structures, most buildings exhibiting some measure of cladding distress will require a more detailed condition survey.

The condition survey may involve close-up inspections of selected building envelope regions and components. Typically, these inspections are conducted partly from the building's interior and partly from a swing stage. Where conditions in the interior of the veneer wall system are to be examined, use of a fibreoptics borescope has been found to be advantageous. After a small hole of about 12 to 20 mm in diameter has been drilled through wall components, the instrument is inserted for a visual scan of the interior of the wall. In cavity wall construction, a borescope investigation thus allows observation of the condition of ties bridging the cavity. By attaching a camera to the end of the viewing rod of the instrument, a photographic record of in-situ conditions can be made.

While the borescope can be an aid in assessing interior wall conditions, additional openings either from the interior or from the exterior of the cladding system are typically required to inspect otherwise hidden conditions. These openings are generally chosen with great care in order to maximize information to be gained, yet minimizing any potential aesthetic and performance problems of the cladding system after closing in the opening. Where brick masonry has to be cut and matching bricks for closing in the opening are no longer available, removal of bricks from less visible areas on the same structure has been found to achieve repairs to the owner's satisfaction. When closing in inspection openings, particular care must be taken to achieve continuity in the air and vapour barrier systems.

## *15.3 CAUSES OF DISTRESS*

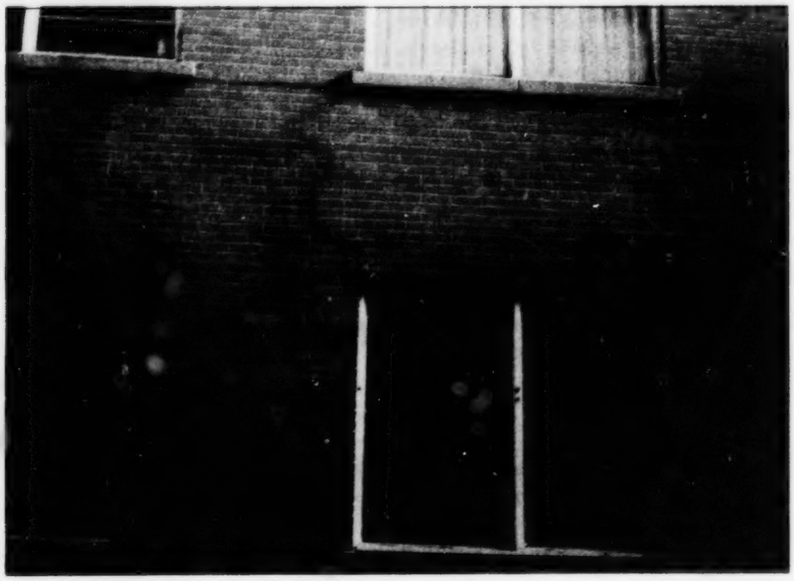
Since BV/CM and BV/SS cladding systems involve a variety of materials, a host of design decisions, and various construction steps under differing climatic conditions, cladding distress may be due to many causes. In essence, though, distress can be viewed as being due to inadequacies in:

- materials;
- design;
- construction; and
- maintenance.

In practice, distress is caused rarely by a deficiency in a single factor but rather by the combined deficiencies in several factors coming into play. For the professional involved in post-construction inspections of BV/CM and BV/SS cladding systems, it may be useful to categorize cladding distress into two key distress categories:

1. Minor distress involving primarily minor problems of serviceability and appearance.
2. Major distress involving problems of safety or major problems of serviceability and appearance.

The following two sections give an overview of typical minor and major distress cases respectively.



▼ Figure 15.2 Vertical brick veneer cracking due to absence of vertical joints to accommodate horizontal movements

## 15.4 SIGNS OF MINOR DISTRESS

Experience has shown that virtually all building envelopes exhibit some signs of minor distress after a few years' performance under Canadian climatic conditions. While this statement holds for all types of enclosure systems, the following comments will be directed specifically toward the BV/CM and BV/SS wall systems. Periodic inspections and maintenance procedures will ensure that minor distress problems involving serviceability and appearance are contained and do not evolve to more major safety problems.

The following listing of signs of minor distress is not meant to be exhaustive but rather illustrative of some typical situations.

### VERTICAL CRACKS IN BRICK VENEER

Such cracks generally indicate either that adequate movement joints (vertical joints) have not been provided or that significant compressive loading is present in the veneer. Inadequate movement joints, illustrated in Figure 15.2, can often be rectified by cutting control joints in alignment with the cracks, replacing badly cracked and chipped bricks, and sealing the joint with caulking on a backer rod. Attempts to seal the crack simply by caulking will not bring about a long-term repair, since the caulking cannot be made to adhere well to the cracked surfaces and the crack is often too narrow to allow penetration of the caulking material.

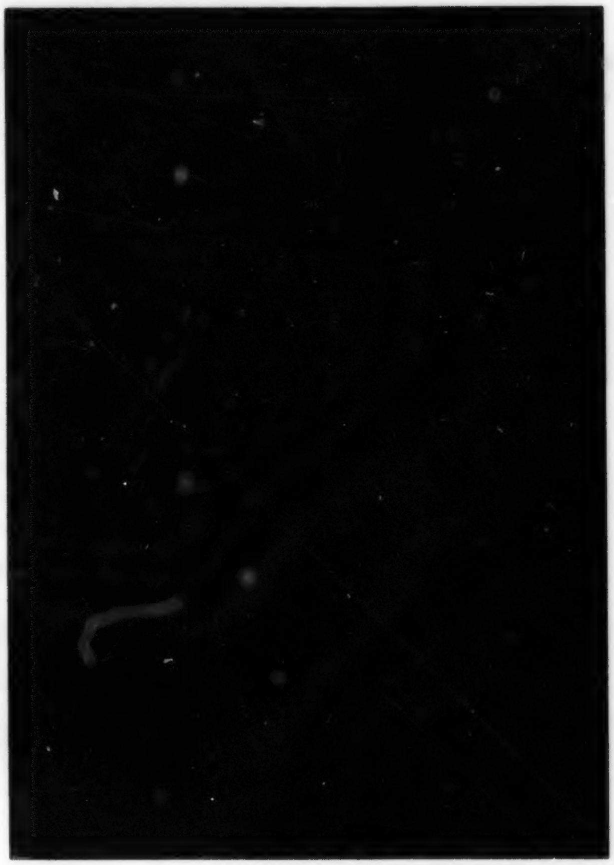
Buildup of significant compressive loading in the veneer, is typically due to absence of a horizontal movement joint at shelf angles. Note that even where a caulked soft joint appears to be present, it is prudent to probe behind the caulking in cases where vertical cracking is evident: there have been too many instances where the movement space behind the caulking was mortared in. Assuming a mortared-in shelf angle condition, distress normally manifests itself by vertical cracking near wall returns as illustrated in Figure 15.3, and by intermittent spalling of the brick in the course above and below the shelf angle location as shown in Figure 15.4. Should bulging of storey height panels also be indicated, major distress is present and this will be discussed in Section 15.5.

Since compressive forces in the veneer due to absence of horizontal movement joints increase towards the bottom of a building, any investigation of distress involving removal of damaged brick should commence at the top of a building. Assuming that a detailed condition survey indicates that the only deficiency is the absence of movement joints at shelf angles and that the buildup of stresses is not very high, repair measures involve the introduction of movement joints at shelf angles and the replacement of spalled and cracked veneer. Typically, however, other deficiencies such as inadequate shelf angle support conditions or missing ties are also encountered. Such signs of major distress are dealt with in Section 15.5.

### *STEPPED CRACKS IN LOW-RISE BRICK VENEER*

Such cracks may be associated with foundation movements. Where foundation movements are due to soil settlement and any additional settlement can be judged as being very small, repair of the cracked veneer can be readily undertaken.

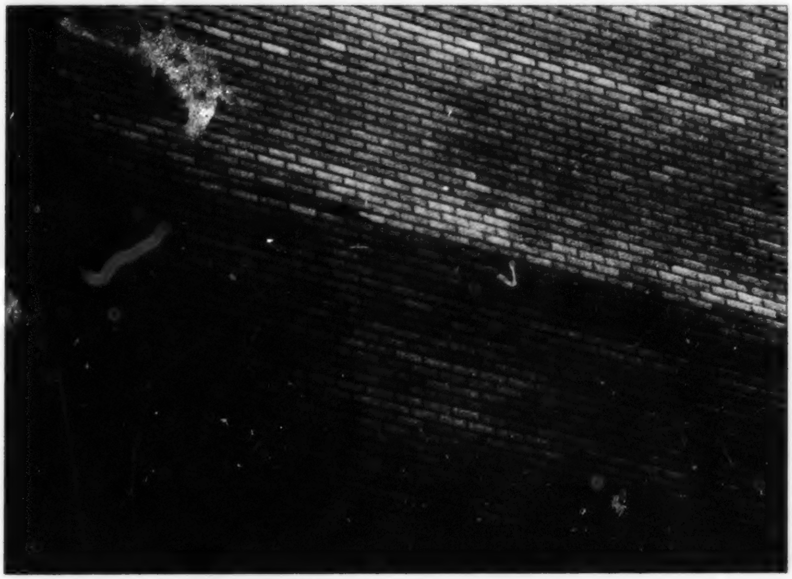
Cyclical foundation movements, for example those due to freeze-thaw action of the subsoil, obviously require specialized remedial measures before the veneer distress can be repaired. Where depth of frost penetration leads to a foundation movement problem, the use of horizontally placed insulation in the surrounding soil has proven to be an economical solution.



▼ *Figure 15.3 Vertical cracking due to buildup of high stresses in the brick veneer caused primarily by the absence of horizontal movement joints*

### *MOISTURE INGRESS AT SLAB LEVEL*

Where the reinforced concrete slab projects through the exterior of the building envelope, moisture is able to penetrate to the interior of the building all too easily. At the top of the slab, the flashing must be heavily relied upon to drain any moisture from the cavity. Inevitable imperfections in the continuity of the flashing and in the required close alignment between exterior slab edge and flashing drip may create moisture paths at the floor level. The situation is worsened by differential deflections and movements between a floor slab and the cladding. These movements can create a cracked joint which readily admits water.



▼ *Figure 15.4 Brick spalling due to high stresses at a mortared-in shelf angle*

Differential movements and construction imperfections between slab and cladding can also permit moisture to flow along the underside of the slab to cause moisture stains and drips on interior ceilings. While the common and cheapest solution is to seal affected areas by means of caulking, all such measures are short-term solutions which, as part of periodic maintenance or emergency repairs, must be repeated time and time again.

Experience has shown that for many Canadian climatic conditions, veneer construction with the slab projecting through to the exterior of the building will require frequent maintenance measures.

### *EFFLORESCENCE STAINING*

The presence of efflorescence, as shown for instance in Figure 15.5, is invariably an indication of moisture migration. When it persists from year to year, it may adversely affect the rental or sales potential of a structure and hence will require remedial actions. The remedial actions taken will depend on whether the moisture is primarily the result of infiltration or exfiltration. While the control of efflorescence has been dealt with in Section 12.5, two additional comments are useful.

First, to control moisture infiltration which can leach salts out of the masonry, surface treatments and coatings are commonly employed. It should be recognized that before carrying out any such measures a careful assessment should be made of the long-term performance of relevant surface treatments and coatings. If inappropriate materials are used, the veneer's appearance may be further adversely affected over the long term.

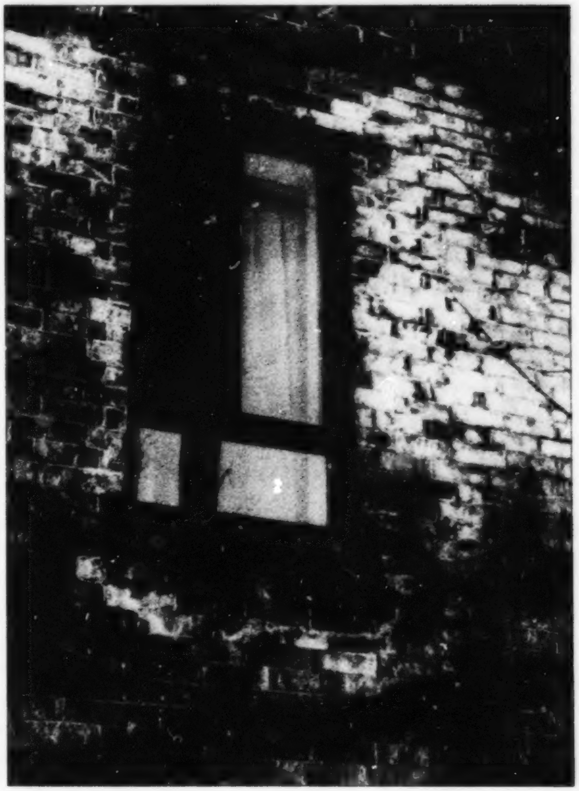
Second, to establish whether infiltration or exfiltration is the primary cause of moisture migration will require a careful assessment of design details and as-built conditions. A potentially weak link in sealing a building enclosure against infiltration and exfiltration is the connection between the wall system and openings. As discussed in Chapters 8 to 10, it is difficult in practice to achieve continuity of air and vapour barriers at such connections. Moreover, interior tracks of sliding windows and doors often do not shed moisture towards the exterior but enable accumulated water to escape into the wall system through small gaps such as at the bottom corners of the track.

## *MORTAR DETERIORATION*

Although today's harder cement-based mortars generally display good durability, mortar deterioration may be a problem under a variety of conditions. The foremost condition involves moisture and freeze-thaw cycling.

Just as the performance of concrete under moist freeze-thaw cycling is improved by air entrainment, mortar which repeatedly is subjected to such extreme conditions should be specially formulated to include an air entraining agent. Although veneer walls are not normally exposed to such severe conditions, nevertheless splash zones near roadways, veneer walls extending to ground level, and other design features, such as poorly placed scuppers which direct moisture unto veneer surfaces, can lead to local mortar deterioration.

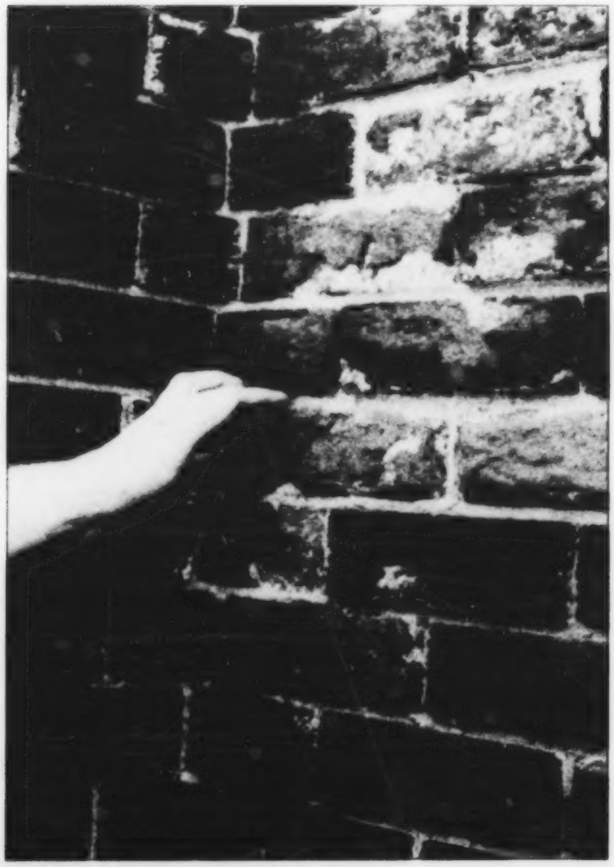
Two other conditions causing mortar deterioration involve (a) first, incorrectly batched mortar leading to a weak mortar, and (b) mortar which is incompatible with the masonry unit and thus leads to cracking at the mortar/unit interface. Weak and cracked mortar can disintegrate rapidly, especially under conditions of erosion from copious amounts of water in combination with freeze-thaw action. Such a case is illustrated in Figure 15.6. To restore deteriorated and cracked mortar, repointing and improvement of certain building details to direct excessive amounts of moisture away from the veneer will typically be required.



▼ *Figure 15.5 Efflorescence staining due to poor continuity of air and vapour barriers around the opening*

### *BRICK DETERIORATION*

Although brick is a very durable material, as discussed in Chapter 13, some clay bricks are susceptible to freeze-thaw deterioration. Since such deterioration depends on the brick being saturated to a high degree, repair measures typically must address not only the replacement of damaged bricks but also the requirement for improved detailing which will prevent the accumulation of excessive amounts of moisture in the clay brick.



▼ *Figure 15.6 Deterioration of mortar and brick due to the combined effects of moisture and freeze-thaw action*

### *WEEP HOLE DISTRESS*

For well functioning veneer wall systems, moisture from the cavity is vented continuously through weep holes and vents. Should weep holes be plugged or omitted altogether, moisture ingress at slab levels can readily occur. Besides flooding floor areas near external walls, damage can result to rugs and furnishings as well as to gypsum wallboard and interior finishes. Also, under cold weather conditions, freezing of water in the cavity may cause lateral pressures to be exerted on the veneer, resulting in outward veneer displacement and cracking distress.

If wetting problems persist over longer periods of time, corrosion of such metal components as the bottom track of the steel stud system may ensue. Occasionally, inspection of veneered walls will reveal significant moisture staining below weep holes. This is an indication that too much moisture is entering the cavity by infiltration, exfiltration, or a combination of the two. Remedial measures must address the source of the moisture to prevent premature deterioration of wall components such as ties, studs, screws, sheathing, and shelf angle.

### *DETERIORATED CAULKING*

Even top quality, properly installed caulking seldom has a service life exceeding 10 to 15 years when exposed to Canadian climatic conditions on the exterior of BV/CM and BV/SS wall systems.

Deterioration manifests itself in many ways: due to aging, the caulking becomes hard and inflexible; the caulking itself is cracked or torn; debonding between caulking and material surfaces has taken place; caulking has been squeezed out of a joint that has closed up due to one-time or cyclical movements. For remedial work, care should be taken to remove all deteriorated caulking and prepare surfaces according to manufacturers' instructions. Similarly, manufacturers' instructions must be carefully followed in installing replacement caulking. In combination with a good-quality caulking material, these steps will ensure a reasonable life for the recaulked joint.

### *15.5 SIGNS OF MAJOR DISTRESS*

Whenever signs of minor distress are evident on the exterior or interior of a veneer clad structure, it is essential, above all, to investigate if otherwise hidden deficiencies endanger the safety of the veneer wall system. Such hidden deficiencies may mean that the apparently minor distress problem is really a major problem potentially endangering the safety of the public.

Perhaps no clear division between minor and major distress can be, and need be, made when problems of serviceability and appearance are encountered. However, based on cost and extent of repairs, extensive efflorescence and brick deterioration problems over large surface areas may well be classified as major distress. Since efflorescence and brick deterioration problems have been dealt with previously, discussion here will focus on major distress cases involving safety. Again, cases mentioned here are not intended to be all-inclusive but rather to illustrate some typical distress situations.

Perhaps the most common, and potentially most dangerous, cladding problem that has surfaced on high-rise structures during the past 15 to 20 years has been caused by the omission of movement joints at shelf angles. This omission has led to major cladding distress in steel and especially reinforced concrete buildings; more so in the latter because differential movements here are greater due to creep and shrinkage of the frame. As very substantial loads are transferred into veneers because of interaction with the frame, distress typically manifests itself in spalling of brick at shelf angle locations, vertical cracking, bulging and, occasionally, the sudden collapse of storey-high panels. While this movement joint problem has been well documented over the past few years and most designers and contractors have become aware of the vital need for the presence of the joint, it is useful to focus briefly on related major deficiencies which have often contributed to the distressed condition of the veneer. Major deficiencies encountered in cladding investigations include the following:

- inadequately fastened shelf angles because of missing bolts, improperly tightened bolts, torch-cut oversized holes, undersized washers, and use of improper shimming material such as wood and bits of brick;
- lack of continuity of shelf angles;
- absence of an adequate number of ties;
- corrosion of ties and other galvanized steel components such as bottom track, steel stud, and screws;
- cracking of CM backup due to absence of a movement joint at the top;
- bulging of SS backup due to absence of a movement joint at the top or bottom;
- improper installation of flashing including torn material and absence of laps;

- presence of extensive mortar fins bridging the cavity and buildup of mortar droppings at the bottom of the cavity;
- blocked weep holes;
- inadequate bearing support of veneer on shelf angle due to large brick masonry overhangs;
- wet insulation and gaps in insulation;
- moisture-softened gypsum wallboard; and
- serious lack of continuity of air and vapour barriers.

When listing these major deficiencies, it should be kept in mind that some stem from the original construction while others are the result of distress of the cladding system over a period of time. Because so many potentially major deficiencies are hidden at the outset of an enclosure investigation, it is vital that any investigation be thorough enough to establish the true extent not only of distress, but also of the potential for unsafe conditions or costly future repairs.

## *15.6 PERFORMANCE OF CLADDING SYSTEMS*

Besides the BV/CM and BV/SS systems, other modern cladding systems used in Canada include materials such as precast concrete, stone, steel, and aluminum. Mention of the wider range of cladding systems is made here because the discussion in the last two sections may have left the impression that the BV/CM and BV/SS systems are prone to performance failure. That would be an erroneous impression indeed.

To the authors' knowledge, both systems have performed satisfactorily and it is, in fact, this satisfactory performance at economic cost which leads to their continued widespread use. Examples of minor and major distress can be cited for all cladding systems, be they those dealt with in this publication or others. Canada-wide environmental conditions acting on cladding systems differ according to regions, yet in a broad sense most Canadian conditions are relatively harsh. For the satisfactory performance of the BV/CM and BV/SS wall systems over the long term, it is important that all aspects of material selection, design, construction, inspection, and maintenance are carried out with due care for the harsh Canadian environmental conditions.

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